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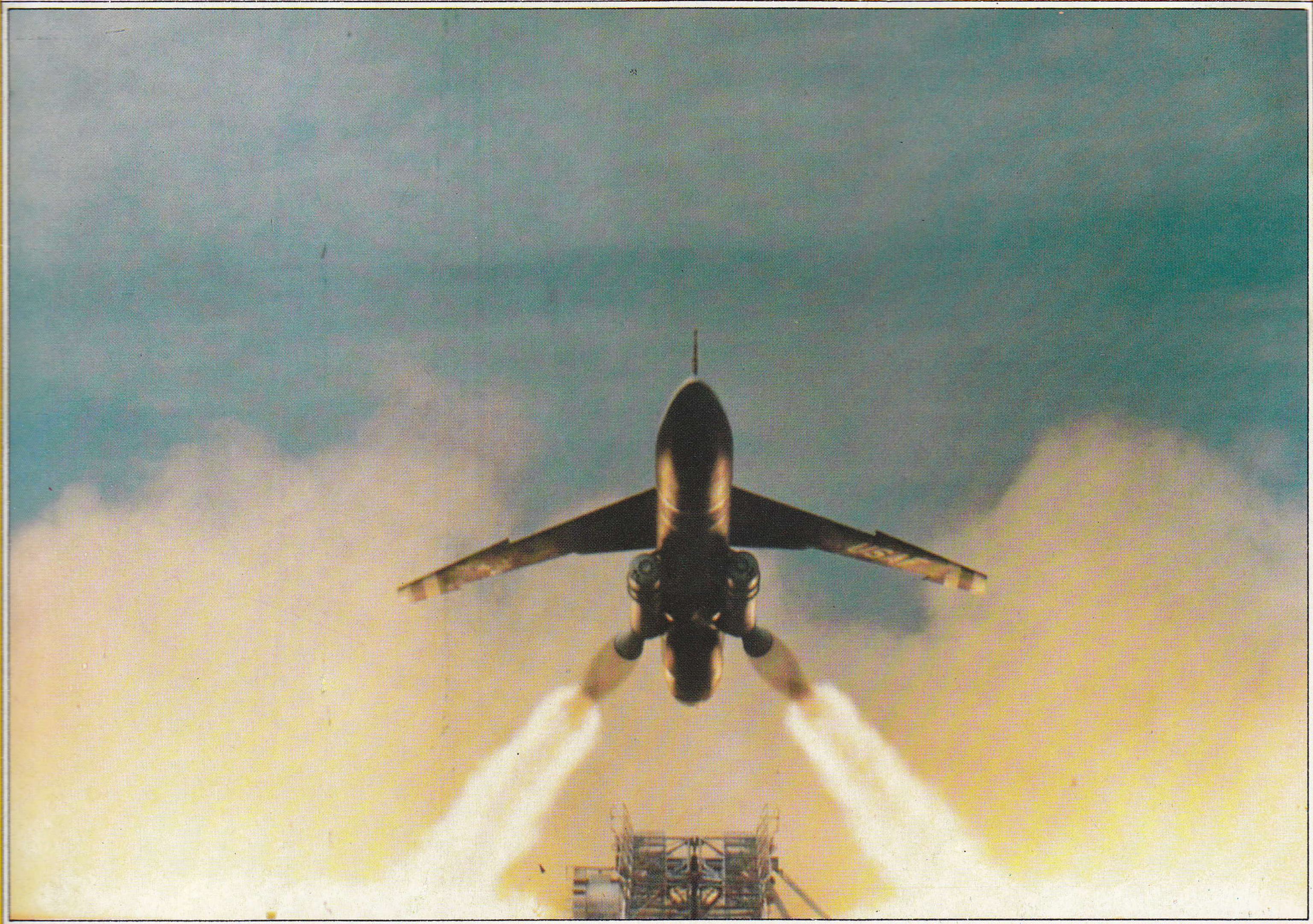

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A fully illustrated guide to Early Strategic Missiles

WAR MACHINE

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Early Strategic Missiles

The introduction of long-range bombardment missiles by Germany at the end of World War II ushered in an era of weapons development which over the last four decades has tested the limits of science, technology and the destructive ingenuity of mankind.

The late 1950s saw the heyday of the strategic cruise missile, with weapons such as the Northrop Snark entering service with the US Air Force's Strategic Air Command. For the next 15 years, however, the ballistic missile proved a more attractive proposition for funding.

While the concept of the guided missile is ancient, it was capable of realization only very recently, because available technology was unable to create an effective guidance system. With the exception of the naval torpedo, no serious guided missile was attempted until well into World War I, and then it was only the air-dropped ones that could do a useful job. What is the point in having a miniature aeroplane packed with explosives and fitted with precision radio command guidance if the man doing the controlling (from a distance of many miles) cannot see the target?

SSMs (surface-to-surface missiles) got into business with the crude but effective 'V-1' described in this study. It was very soon partnered in action by the totally different 'V-2', and these were made possible only by the fact that precision guidance was not attempted; their targets were entire cities. In both cases, however, the missiles incorporated the germ of an idea for self-contained guidance which in the course of many years could become super-accurate. Perhaps remarkably, today we have modern successors to both these pioneer SSMs, using descendants of both their guidance methods.

The successors of the V-1 are called cruise missiles, and they have enjoyed augmented interest since 1977 when it was proclaimed by President Carter as a completely new idea which suddenly rendered the B-1 bomber unnecessary!

During the previous 25 years the cruise missile took a back seat, though both the TM-76 Mace and SM-62 Snark went into service with the USAF and the Regulus I and II both became operational aboard submarines of the US Navy. Partly on the score of vulnerability such weapons faded from the scene after 1960, astronomical sums having been spent instead on every conceivable kind and size of ballistic missile. All in some degree descended from V-2, these wingless projectiles are normally launched standing vertically upright, which has often made it difficult to achieve mobility, quick reaction time and high rate of fire.

Except for the brilliant Blue Water (which, being British, was inevitably cancelled), all the ballistic missiles featured in this analysis were powered by liquid-propellant rocket engines. This meant complexity, potential unreliability and the use of extremely toxic and corrosive acids and/or intensely cold liquefied gases. The latter could not even be pumped into the missile until it was wanted for firing, and in the case of weapons as large as SS-6 and Atlas it meant that the reaction time could hardly be less than half an hour.

The first ICBMs required elaborate fixed launch sites. Often the only fully-equipped test facility was Cape Canaveral, with day and night launches becoming a great tourist attraction.

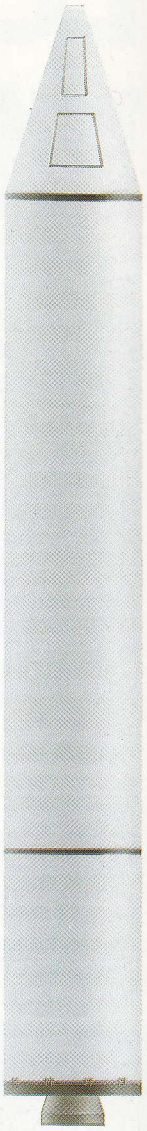
USA

Chrysler Jupiter

Throughout the 1950s the US Army Ballistic Missile Agency at Redstone Arsenal was the world's most experienced source of large ballistic missiles. It was natural that in 1954 development should have started on a new missile of the much longer range which had become technically possible. This was named **Jupiter**, was the first IRBM (intermediate-range ballistic missile), and was a logical extension of A4/Redstone technology to a design range of 2776 km (1,725 miles). In 1955 plans were studied for a US Navy version for tube launch from various ships, notably large submarines. The basic vehicle was actually shorter than the Redstone, but of greater diameter, and its enormous tankage section was made by welding extruded panels of aluminium alloy. From its flat base protruded the thrust chamber of the engine, which was much more powerful and advanced in design than any predecessor. It pivoted on gimbal mounts to vector the thrust to steer the missile in any direction, roll control being effected by vectoring the turbopump exhaust pipe. For the first time the speed on re-entry to the atmosphere was so high that a special nosecone was needed to protect the warhead; an ablative type was selected, much lighter than the heat-sink type chosen by the USAF. An excellent feature was that it was a mobile system, towed to the launch site and there erected by a cable-hoist, a much smaller and neater system than the Redstone method. A folding petal-type shelter covered the lower part of the missile during pre-launch preparation and fuelling. The first definitive missile was launched on 1 March 1957, a full-range mission came in May, and by January 1958 Jupiter was declared operational. But in November 1957 the US government decreed that the US Army should not develop weapons of over 322-km (200-mile) range, and Jupiter became **SM-78** (later **PGM-19A**) of the US Air Force. The 864th and 865th Strategic Missile Sqns took 30 missiles each to Italy and Turkey in 1960, and subsequently trained units of the host air forces until deactivation in 1965.

Specification

Jupiter
Type: mobile IRBM
Propulsion: one Rocketdyne S-3 engine rated at 68040-kg (150,000-lb) thrust and burning liquid oxygen and RP-1 kerosene
Performance: burn-out speed Mach 12; range 3180 km (1,976 miles)
Weight: launch 49895 kg (110,000 lb)
Dimensions: length 18.31 m (60 ft 0.9 in); diameter 2.68 m (8 ft 9.5 in)
Warhead: thermonuclear, up to 1.5 megatons
Guidance: inertial
Control: thrust vectoring of main engine and turbopump exhaust, with vernier velocity trimming by small motor on re-entry vehicle



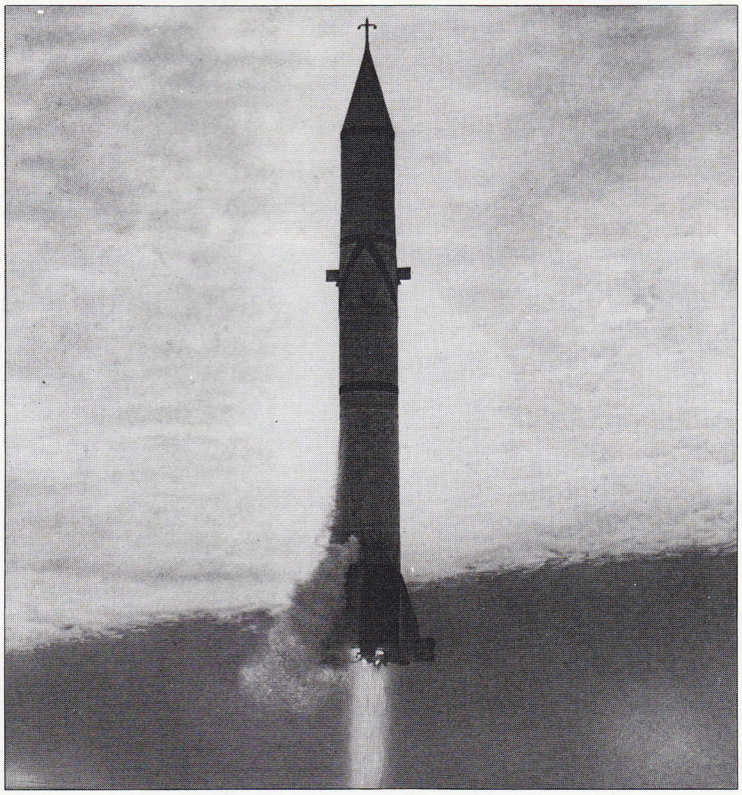
Right: Powered by a gimbal-mounted motor more advanced than any previous system, the 3180-km (1,975-mile) ranged Jupiter was the world's first operational intermediate range ballistic missile (IRBM).

USA

Chrysler Redstone

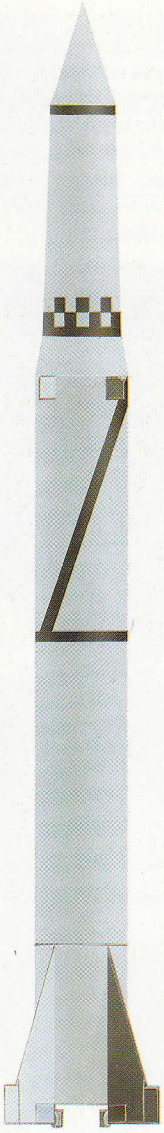
This enormous ballistic rocket was the most direct descendant of the pioneer wartime A4 (V-2). This was natural, because its design team at the newly formed US Army Ballistic Missile Agency (ABMA), at Huntsville, Alabama, was composed of the same German engineers that developed the A4, working under von Braun. The name came from the original US Army organization at Huntsville, Redstone Arsenal. Over 500 US civilians also participated, including most of the General Electric team from Project Hermes and a few Convair MX-774 engineers. Though based on the A4, the **SSM-A-14 Redstone** (US Army designation **M5**) had slightly greater diameter, much greater length, totally new guidance and a separable nosecone and forebody with small wedge-like control fins. It was a great technical achievement, though today it seems clumsy and inconvenient. At least the ancestry ensured that the Redstone was mobile and not installed in vast fortresses of concrete. Weighing over 250 tons, the system included a gigantic A-frame derrick and winch with which the missile could be slowly pulled upright on to its rotating ring launcher. This then had to be turned to the exact azimuth setting for the selected target. Four enormous trailers contained a liquid-oxygen plant with an output of 20 tons per day, while other huge Fruehauf transporters carried the warhead section, tankage section and motor section which then had to be assembled at the launch site. No vernier motor was used for precision trimming of the final velocity, so the cut-off timing of the main motor had to be extremely accurate if the impact was to be on target. The first test firing was on 20 August 1953, and the first US Army unit, the 40th Field Artillery Missile Group (Heavy), was activated in July 1957. Production of 1,000 rounds was handled by Chrysler's Defense Operations Division. In the 1962 designation system Redstone became **PGM-11A**.

Below: The Redstone used German A4 (V-2) technology. Many of the design team had worked on the German programme, and under Wernher von Braun were to provide the backbone of American missile research in the 1950s and 1960s.



Specification

Redstone
Type: heavy guided artillery missile
Propulsion: one North American Aviation (Rocketdyne) A-6 rocket engine with turbopump feed of liquid oxygen and alcohol for sea-level thrust of 34019 kg (75,000 lb)
Performance: cut-off speed for maximum range typically 5472 km/h (3,400 mph); maximum range variable with warhead to 401 km (249 miles), but US Army prohibited by Wilson Memorandum from deploying weapon with more than 322-km (200-mile) range; see Jupiter entry
Weights: empty 5080 kg (11,200 lb); launch 27987 kg (61,700 lb)
Dimensions: length (late PGM-11A) 21.03 m (69 ft 0 in); body diameter 1.78 m (5 ft 10 in); fin span 3.66 m (12 ft 0 in)
Warhead: up to 2994 kg (6,600 lb) nuclear
Guidance: Ford Instrument (Sperry Rand) inertial, first use of air-bearing gyros
Control: refractory jet deflector vanes, tail fins, precision cut-off of propulsion, and control vanes on descending warhead section

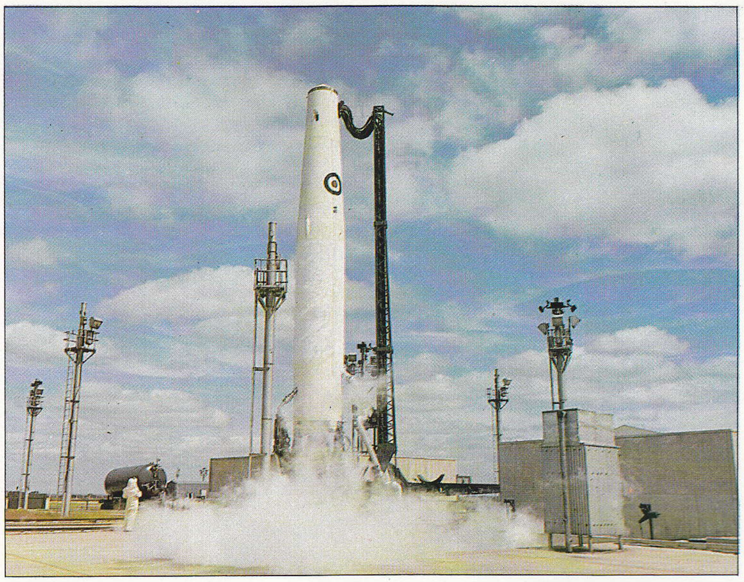


The 27-ton Redstone had a maximum range of 400 km (250 miles), which was not much more than the original V-2. The major difference, of course, lay in the carriage of an atomic warhead.

USA

Douglas Thor

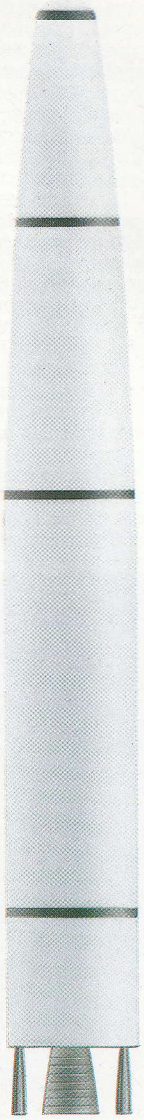
One of the worst cases of inter-service rivalry in history resulted in the USAF, which had previously disbelieved in such things, being urgently authorized in 1955 to develop an IRBM (intermediate-range ballistic missile). The already existing IRBM of the US Army (Jupiter) was also transferred to the US Air Force, which promptly gave priority to its own missile; this was the **SM-75 Thor**, part of the giant Weapon System 315A. Unlike the Jupiter, this was planned for use from vast fixed sites, where it was completely vulnerable. The tankage sections were assembled from chem-milled aluminium panels, carrying at the bottom a large gimballed main engine flanked by two vernier engines (burning the same propellants) whose function was to provide roll control and, after main-engine cutoff, vernier trimming of the velocity along the desired trajectory. The warhead was housed in a separable RV (re-entry vehicle) protected by a heavy copper heat sink. Douglas Aircraft received the contract to develop WS-315A on 27 December 1955, finished the design in July 1956 and delivered the first missile to the USAF in October 1956, a timing never since equalled (and the whole thing was uncharted waters). The system was declared operational in 1959, and RAF Bomber Command activated 20 squadrons, each with three launch complexes, with all hardware airlifted across by Douglas C-124 or Douglas C-133 transports to bases extending from Yorkshire to Suffolk. After 1962 the missile was redesignated **PGM-17A**, the trainer version being **PTM-17A**. As this was a soft fixed-site weapon system, unlike Jupiter, it was obviously completely vulnerable and the RAF sites were deactivated from 1965. Thors were subsequently rebuilt into Delta space launch vehicles.



Above: The early 1960s saw RAF Bomber Command operating some 60 missiles in 20 squadrons along the east coast of England. Its deployment on fixed launch sites made Thor much more vulnerable than the rival Jupiter system developed by the US Army.

Specification

Thor
Type: fixed-site IRBM
Propulsion: one Rocketdyne LR79 gimballed main engine rated at 68040-kg (150,000-lb) thrust and burning liquid oxygen and RP-1 kerosene, plus two LR101 vernier motors
Performance: burn-out speed Mach 12; range 2779 km (1,727 miles)
Weight: launch 47627 kg (105,000 lb)
Dimensions: length 19.81 m (65 ft 0 in); diameter 2.44 m (8 ft 0 in)
Warhead: thermonuclear, up to 1.5 megatons
Guidance: inertial (Improved AChiever system, with floated gyros)
Control: thrust vectoring of main engine, with precision trimming of cut-off velocity by vernier engines



Thor had a maximum range of 2780 m (1,727 miles) and was launched from fixed sites, unlike Jupiter. Roll control and attitude trimming were maintained by two small vernier motors on each side of the main gimballed engine. It was also used for satellite launches, when the warhead was replaced by a longer nose cone containing a payload.

Above: A Thor-Able II is launched from Cape Canaveral to test space vehicle nose-cone design and re-entry. By 1958 such missions were regularly undertaken by converted ballistic missiles such as the Thor.

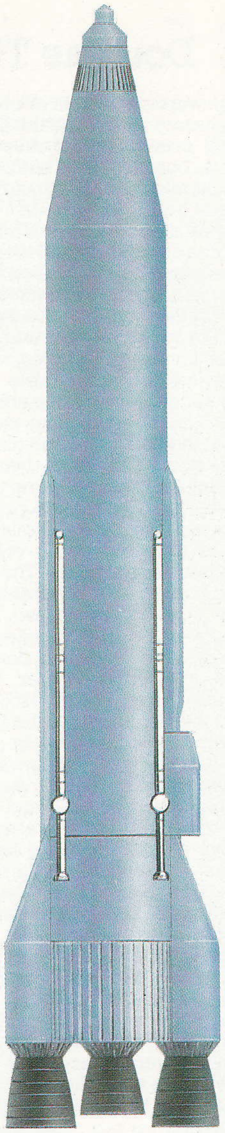
Below: In February 1960 at RAF Feltwell a Thor missile of No. 77 Squadron, Bomber Command, is raised to its operating position. The vulnerability of such fixed targets, unhardened against nuclear attack, and the need to maintain an effective deterrent led to a somewhat curtailed RAF career for Thor, with de-activation in 1965.

Above: A pre-production Thor is launched just prior to the type's operational deployment with missile squadrons of the US Strategic Air Command (SAC). An IRBM, the Thor had to be based within striking distance of the main potential enemy, which meant European basing with the Soviet Union as prime target.

USA

General Dynamics Atlas

Once mathematician John Von Neumann and the 'Teapot Committee' had shown in 1953 that an ICBM was not only technically possible but could be created in six years, the USAF assigned gigantic forces to do just this with Weapon System 107A. The missile portion was the **SM-65 Atlas**, developed by GD Convair Astronautics under Karel J. Bossart. Its unusual features included a vast tankage section made of stainless steel so thin it had to be continuously pressurized, like a balloon. To avoid the challenge of starting a giant rocket engine in space all five engines were started on the ground. Centred under the conical bottom of the tankage was the sustainer engine. Surrounding it was a skirt section containing two even more powerful boost engines, mounted on gimbals and hydraulically vectored to control the trajectory. Well up on each side was a vernier engine. About 145 seconds after lift-off the entire boost section was jettisoned. The sustainer and verniers then burned for about another 190 seconds, the verniers trimming the exact final velocity according to the guidance information housed in large fairings down each side. The RV (re-entry vehicle) was initially a massive blunt copper heat-sink, but later missiles had a slim General Electric ablative cone. First flight (without sustainer) was on 11 June 1957. By 1960 Strategic Air Command's giant launch complex at Francis E. Warren AFB was in business. This soft above-ground system was followed by semi-hard 'coffin' installations, and finally by hardened silos (a new idea), the cryogenic liquid missiles having to spend over 30 minutes at the surface before lift-off. After 1962 the nine versions of missile were given new designations, such as **CTM-16D** and **CTM-16E** (trainers) and **HGM-16F** (a combat version). In 1965-7 the whole force of 117 was deactivated, the missiles being rebuilt into space launchers.

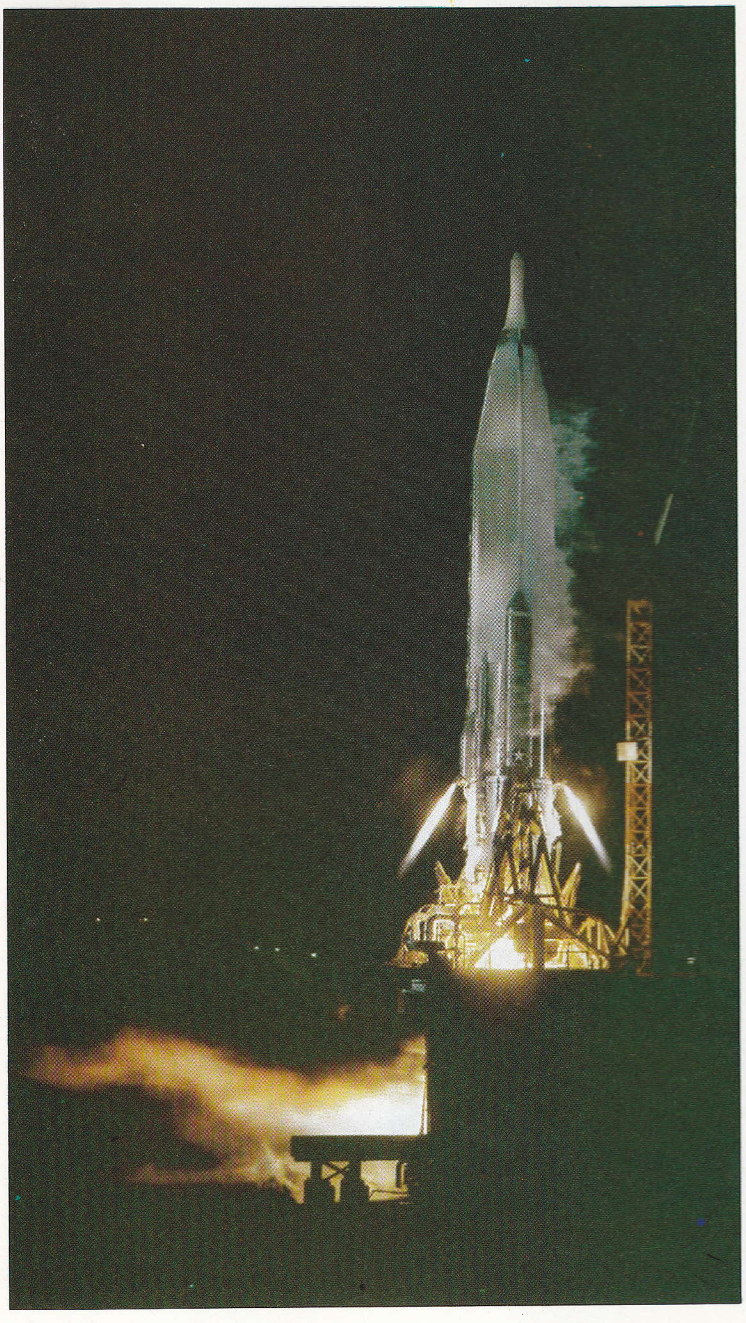


The first American ICBM, the General Dynamics SM-65 Atlas, was powered by one central sustainer engine flanked by two even more powerful booster engines. The nose cone was changed when thermo-nuclear warheads were fitted.

Specification

HGM-65F Atlas

Type: fixed-base hardened ICBM
Propulsion: one 25855-kg (57,000-lb) thrust Rocketdyne LR89 sustainer engine, two 74845-kg (165,000-lb) thrust Rocketdyne LR105 boosters and two 454-kg (1,000-lb) LR101 verniers, all burning liquid oxygen and RP-1
Performance: cut-off speed Mach 27; maximum range 18507 km (11,500 miles)
Weight: launch 117934 kg (260,000 lb)
Dimensions: length 25.15 m (82 ft 6 in); diameter (excluding side boxes) 3.05 m (10 ft 0 in)
Warhead: thermonuclear, usually 3 megatons
Guidance: inertial (Bosch Arma)
Control: thrust vectoring of sustainer and boosters, with velocity trim by verniers



Left: The night launch of an Atlas with a General Electric ablative nose cone demonstrates the practice of launching the missile with all engines in operation. In addition to the sustainer and two boosters, both manoeuvring vernier engines are clearly visible.

Below: A Boeing B-52 of SAC overflies an Atlas ICBM on the launch pad at the USAF aerospace centre, Vandenberg AFB in California. The Atlas is an early model, with a thermo-nuclear warhead in a massive copper re-entry vehicle.

USA

Martin Titan

By 1955 the USAF and the US Strategic Missiles Evaluation Committee could see that the original ICBM systems, WS-107A and its Atlas missile, could be improved upon. A second ICBM also seemed prudent as an insurance. Accordingly a giant contract was awarded to The Martin Company, which at its specially created Denver division produced the **Martin SM-68 Titan**, using the same liquid oxygen and RP-1 propellants but with two separate stages of propulsion, one above the other. The second-stage engine had two thrust chambers of 25:1 nozzle expansion ratio for use only in vacuum space conditions. Unlike that of the Atlas, a thick-walled light-alloy airframe was used, able to stand upright unpressurized, with tanks empty, at the bottom of its hardened silo. Nevertheless, the huge missile had still to be hoisted to the surface empty and its propellants pumped aboard before it could be fired. At first inertial guidance was chosen, but in 1958 this system was switched to the Atlas and the Titan weapon system, WS-107A-2, redesigned with cumbersome but possibly more accurate radio-inertial command guidance. The first **SM-68A** series missile, with an inert water-filled second stage, flew on 6 February 1959. Many **SM-68B, C, J** and **M** series missiles followed, and by 1960 the 395th SMS (Strategic Missile Squadron) was making indoctrination and silo-compatibility firings. In 1961-3 SAC deployed 54 missiles, by then called **HGM-25A**, in three triple underground complexes at six locations. A short three years later all had been refilled with the **LGM-25C Titan II** because, despite super-rapid propellant loading, the Titan I still had to spend 15 or more minutes at the surface before launch. The Titan II used new non-cryogenic liquids that could be left for years in the missile, which could thus be fired from the bottom of the silo.

Specification

Titan I

Type: hardened silo-based surface-launched ICBM

Propulsion: (1st stage) one Aerojet LR87 twin-chamber rocket motor of 176078-kg (300,000-lb) sea-level thrust and (2nd stage) one Aerojet LR91 rocket motor of 36287-kg (80,000-lb) vacuum thrust

Performance: cut-off speed Mach 26; maximum range (Mk 4 RV) 14806 km (9,200 miles)

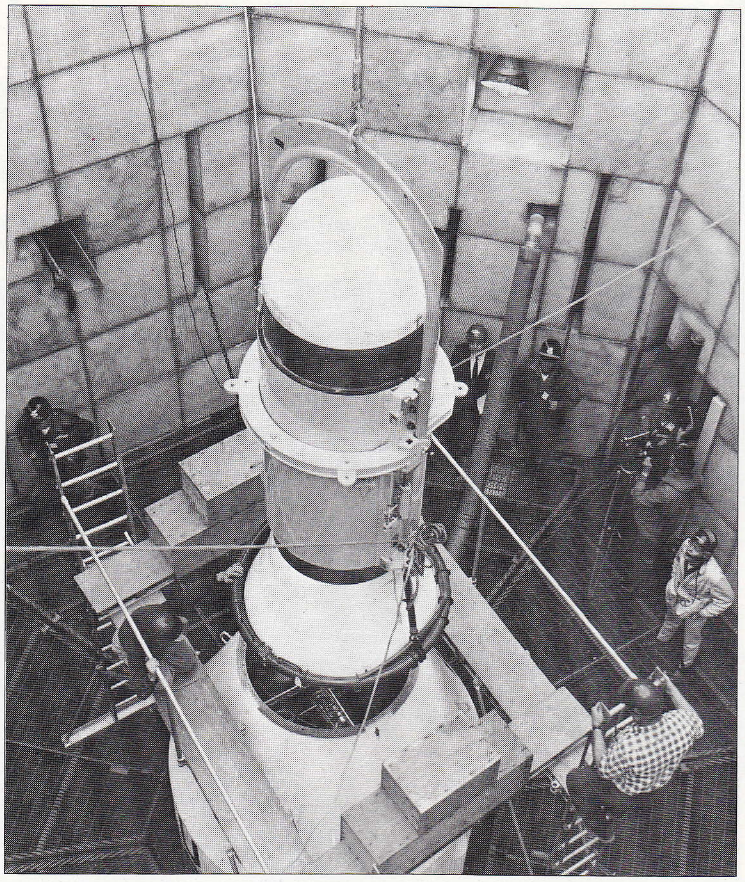
Weight: lift-off 99790 kg (220,000 lb)

Dimensions: length 29.87 m (98 ft 0 in); diameter (1st stage) 3.05 m (10 ft 0 in) and (2nd stage) 2.44 m (8 ft 0 in)

Warhead: (Mk 4 RV) thermonuclear, 4 megatons

Guidance: initially radar/radio plus inertial, later pure (AChiever) inertial

Control: thrust vectoring of main 1st/2nd-stage engines, plus roll control and vernier velocity control by vectoring four 2nd-stage turbopump exhaust nozzles

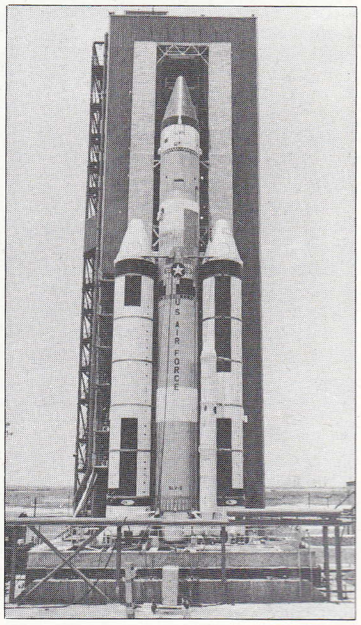


Carefully handling their awesome charge, a crew lowers the four-megaton thermonuclear warhead onto a Titan I missile in its silo.

Handicapped by the need to fuel the missile before launch, Titan II was developed shortly after; this could be launched at short notice.

Right: Developed shortly after the Atlas ICBM, Martin's Titan was a very different missile. Larger than Atlas, it was much more robustly built, and could be safely kept for long periods in silos. It still required to be fuelled before launch, however.

An early Titan II is launched in 1964 at Cape Kennedy in Florida. The Titan II was much improved, its non-cryogenic propellants allowing silo launch without the 15-minute delay required to prepare previous missiles with their super-cooled fuel.

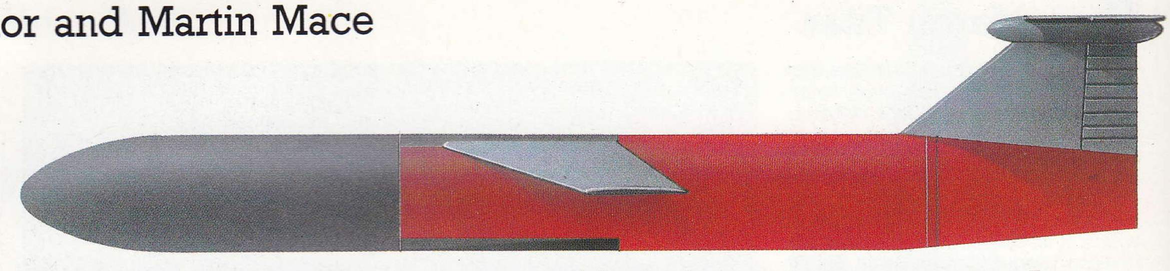


Above: The size and power of Titan made it a natural for use in the space programme, and Titan III was a mainstay of early NASA programmes, launching the manned Gemini missions. This missile was being prepared for launch in October 1965.

USA

Martin Matador and Martin Mace

During World War II the US Army Air Force managed a wealth of cruise-missile programmes, but none survived beyond 1946. One of the replacements was a bigger and more powerful pilotless bomber, the **Martin XB-61**. Started in August 1945, it was not until July 1950, a month after the start of the Korean War, that Martin (at that time Glenn L. Martin Aircraft) was able to complete design of the **B-61A** (later redesignated **TM-61A**, for tactical missile) **Matador**. Constructed of metal-honeycomb sandwich, this weapon resembled a pilotless jet fighter, with a high wing, T-tail and turbojet fed from a dorsal flush inlet. It was designed to blast off under the thrust of a giant solid-propellant rocket from either a mobile launch ramp or a hardened (blast-protected) shelter. Various forms of complex radio guidance were used, and over 1,000 were delivered, one wing becoming operational in West Germany in 1956. By this time the Matador had been replaced in development by the **TM-76 Mace**, with much greater fuel capacity, a larger nuclear warhead and either of two completely new guidance systems in the **TM-76A** and **TM-76B** versions. Large numbers were in service from 1959, one version being deployed from mobile convoys exactly like those now used for 'Cruise'. Operational wings were based as far apart as West Germany and Okinawa, but the Mace was withdrawn in 1966 in the belief that cruise missiles were obsolete.



The Martin TM-76 Mace was to all intents and purposes a pilotless bomber, armed with a nuclear warhead. The 13.41-m (44-ft) long missile was powered by a turbojet with a flush inlet dorsally mounted.

Ostensibly a tactical missile, Mace had a range of some 1328 km (825 miles). Based in West Germany, this range gave the missile a strategic capability. One method of deployment was a system of mobile convoys exactly like the modern cruise missile.

Specification
TM-76 Mace
Type: tactical (or strategic) cruise missile
Propulsion: launch by one large solid-propellant rocket boost motor of 45360-kg (100,000-lb) thrust; cruise propulsion by one 2359-kg (5,200-lb) thrust Allison J33-A-41 short-life turbojet burning normal JP-1 kerosene
Performance: cruising speed 1046 km/h (650 mph) or Mach 0.9; range (typical) 1328 km (825 miles); cruise height from sea level to 13410 m (44,000 ft)
Weights: empty 3044 kg (6,710 lb); launch (excluding boost rocket) 8165 kg (18,000 lb)
Dimensions: span 6.98 m (22 ft 11 in); length 13.41 m (44 ft 0 in)
Warhead: nuclear
Guidance: (TM-76A) Goodyear ATRAN (Automatic Terrain Recognition And Navigation) terrain-comparison and contour-matching or (TM-76B) AC Spark Plug AChiever inertial system
Control: autopilot and conventional ailerons, elevators and rudder

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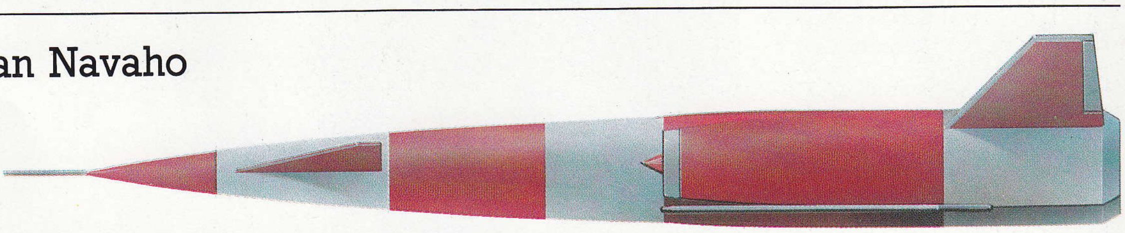
USA

North American Navaho

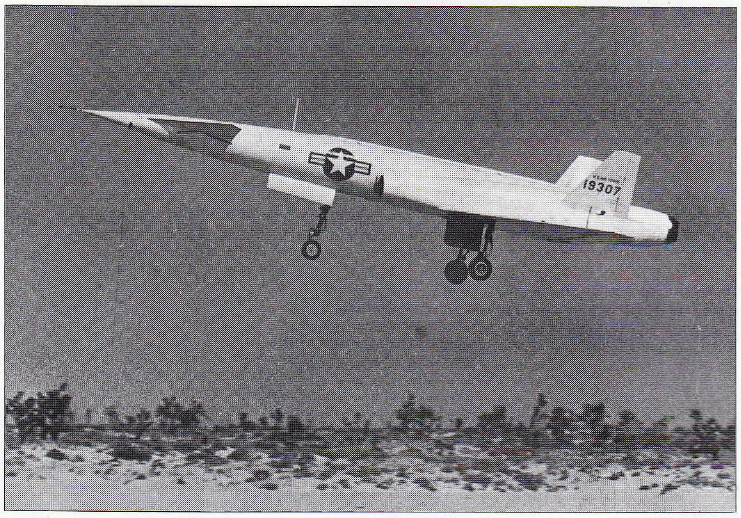


The Navaho stretched the limits of aviation technology, cruising at Mach 3.25 at altitudes of 22860 m (75,000 ft). The 10179-km (6,325-mile) range made the Navaho a true intercontinental weapon.

Today all but forgotten, the **North American Navaho** was a vast cruise missile and the subject of the biggest development contract the world had seen up to 1957, with a single award by the USAF to North American Aviation of $691 million. This huge sum was needed to pay for not just the **SM-64** missile, or even the gigantic Weapon System 104 of which it was a portion, but also much of the guidance, structures and propulsion technology needed for the very different ICBMs which replaced it, notably including the pioneer Rocketdyne engine used up to the present day. The vehicle itself, preceded by flying a series of slightly smaller **X-10** recoverable test vehicles which proved the sandwich structure, canard configuration with butterfly tail, inertial guidance and many other features, was seen as the best way to deliver a thermonuclear warhead over intercontinental distances. This was at the start of development in 1947 when the ICBM was thought impossible of attainment. Roughly twice as heavy as any airliner of the period, the missile was launched vertically, riding piggyback on a giant booster filled with lox/kerosene fed to three of the biggest rocket engines then contemplated. The combined vehicles arched over gently into a programmed climb, accelerating until the missile's own gigantic ramjet engines could be ignited. Then the booster, twice as big as a V-2, was jettisoned, the Navaho continuing to climb to a cruise altitude of some 22860 m (75,000 ft). After tremendous technical problems had been overcome by 1957, it was finally judged that the ICBM would be possible of attainment in the near term and would be superior, and WS-104 was cancelled on 11 July of that year. Existing missiles were used on ICBM support programmes, and on 18 November 1958 one flew a flawless mission over the design range.

Specification

Navaho
Type: intercontinental-range cruise missile
Propulsion: launch by separate boost system with three lox/RP-1 rocket engines with a sea level thrust of 188241 kg (415,000 lb); cruise propulsion by twin Curtiss-Wright RJ47 ramjets integral with the rear fuselage
Performance: cruising speed 3460 km/h (2,150 mph) or Mach 3.25; normal cruise altitude 18290-24385 m (60,000-80,000 ft); range 10179 km (6,325 miles)
Weight: lift-off (SM-64A) 131542 kg (290,000 lb)
Dimensions: span 12.27 m (40 ft 3 in); length (missile) 26.62 m (87 ft 4 in) or (with booster) 29.03 m (95 ft 3 in); fuselage diameter 1.83 m (6 ft 0 in)
Warhead: thermonuclear
Guidance: North American Autonetics inertial system
Control: wing elevons, foreplanes and V-type butterfly tails

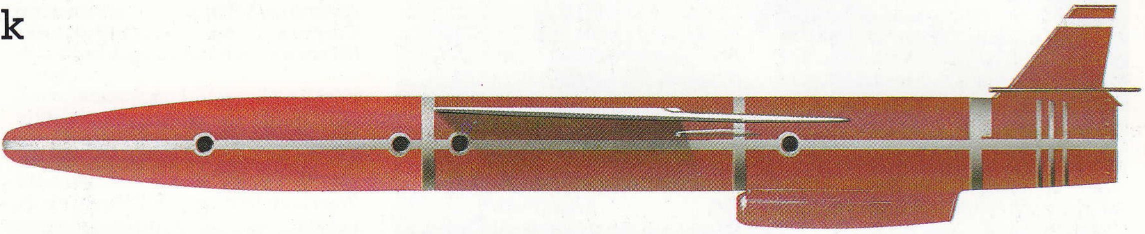


The X-10 recoverable test vehicle proved many of the Navaho concepts, such as the advanced sandwich construction. The canard wing layout and twin butterfly tails were also proven, reappearing on the most advanced fighting aircraft of the 1970s and 1980s.

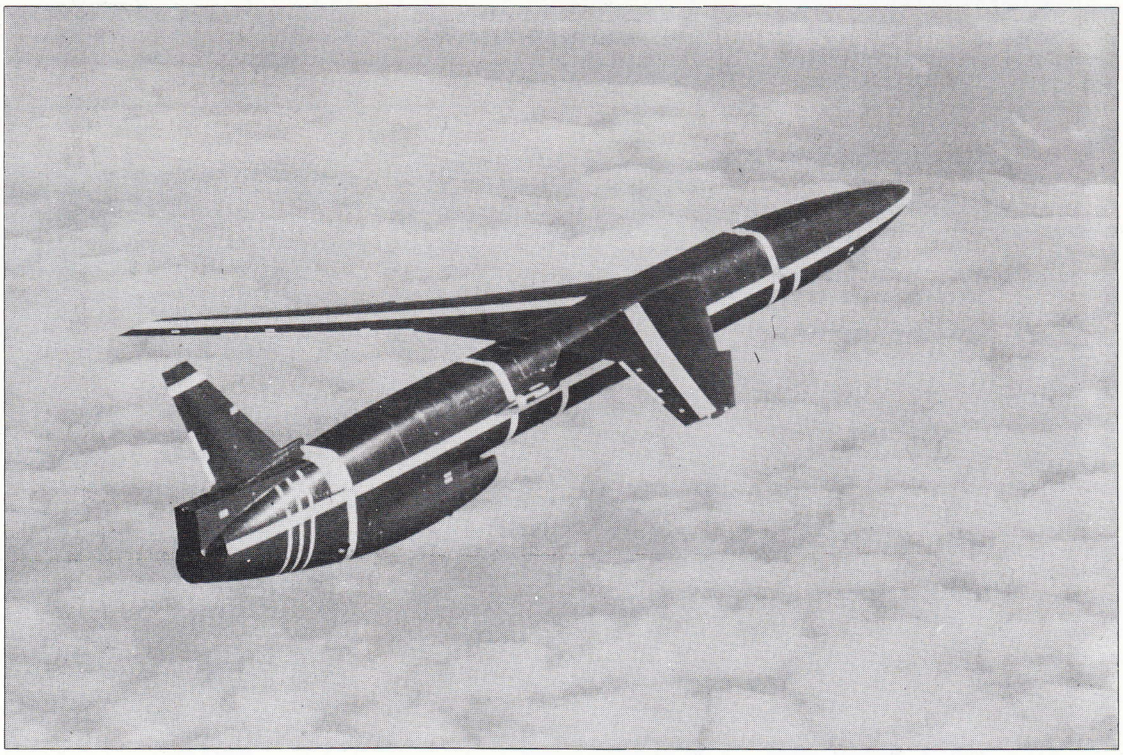
USA

Northrop Snark

The first strategic missile to go into service anywhere in the world, this large cruise missile took 11 years to develop (the first five at low pace, with small budgets) from 1946 to 1957; then at last it got into service with USAF Strategic Air Command, only to be deactivated two years later. Prime contractor throughout was Northrop, and the **Northrop SM-62 Snark** posed major challenges. The configuration adopted was that of an extremely efficient aeroplane with a high-mounted swept wing of advanced aerodynamic form, and without a horizontal tail. Following prolonged testing of **N-25** test vehicles, the big **N-69** first flew on 6 August 1953, powered by the most efficient turbojet available, fed via a ventral inlet. The big fuselage housed 11793 kg (26,000 lb) of kerosene fuel, the Nortronics inertial guidance with automatic periodic updating by a star tracker programmed to take 'sextant shots' of selected stars, and the comprehensive electronic control and accessory systems. After being blasted from its huge mobile launcher, the **SM-62A Snark** climbed out to sea at a constant Mach 0.93 to cruise altitude, typically over 14630 m (48,000 ft). When the guidance system indicated that the correct point in space had been reached it sent a signal severing the entire nose section, which would plunge towards the target with the warhead and, from 1960, penetration aids such as chaff. The rest of the missile would pitch up violently and break up under air loads. All parts of the system were transportable in the Douglas C-124 and SAC squadrons, led by the 556th Strategic Missile Squadron at Presque Isle, Maine, could fire within an hour of arriving at any clear patch of ground. The quip 'Snark-infested waters' was common on the Atlantic Missile Range before 1956, but by the time the 556th was renumbered the 702nd SMS in July 1959 this intercontinental weapon was not only reliable but could take evasive action and approach its target at any height and from any direction.



End result of an 11-year development programme, the Northrop SM-62 Snark was an aerodynamically advanced pilotless aeroplane with a range of 10179 km (6,325 miles). It was the world's first operational strategic missile.



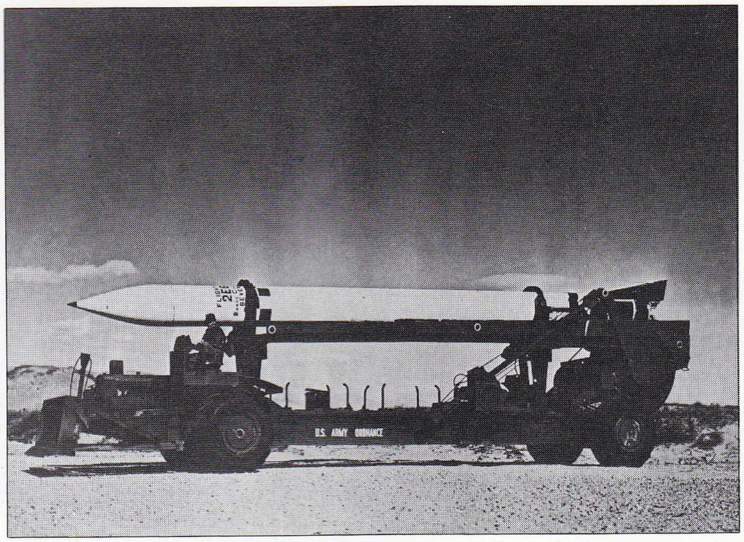
Entering service in 1958, the Snark originally operated at altitudes of 14630 m (48,000 ft) but by 1960 could make low-level attacks, approaching targets from different directions, and was equipped with penetration aids (penaids) such as chaff to confuse defending radar systems.

Specification

Snark
Type: intercontinental cruise missile
Propulsion: launched by two 58967-kg (130,000-lb) thrust rocket motors with vectoring nozzles for initial trajectory control; cruise propulsion by one 4763-kg (10,500-lb) thrust Pratt & Whitney J57-P-16 turbojet
Performance: cruising speed Mach 0.93, at high altitude 990 km/h (615 mph); range 10179 km (6,325 miles)
Weights: empty 12928 kg (28,500 lb); launch (excluding boost motors) 27216 kg (60,000 lb)
Dimensions: span 12.88 m (42 ft 3 in); length 23.10 m (75 ft 9.5 in); wing area 30.56 m^2 (329 sq ft)
Warhead: 2268-kg (5,000-lb) thermonuclear, yield 5 to 20 megatons
Guidance: self-contained stellar-inertial
Control: wing elevons, with asymmetric elevon movement later replacing rudder (which was deactivated)

USA

Firestone Corporal



Concurrent with US programmes to develop strategic missiles, the US Army also produced tactical guided missiles. The first to enter service since World War II was the Firestone Corporal. It could be armed with an HE or tactical nuclear warhead.

Originally known by the US Army designation **M2**, the **Firestone Corporal** was the first ballistic (wingless) missile to go into service outside Nazi Germany. It stemmed from a research vehicle named **Corporal E** built in 1947-50 to test propulsion and guidance systems, and particularly rocket engines that did not use cryogenic (refrigerated) liquids. In 1951 this extremely slender vehicle was hurriedly developed, mainly by the Firestone company, into a military weapon with the US Army and US Navy designation **SSM-A-17** (17th Army SSM model). In effect it was planned as a modernized V-2 operated in the field as a piece of super artillery with a calibre of 762 mm (30 in), large enough for the warhead to be a kiloton-range nuclear device if necessary. Inevitably, the entire weapon system was large and cumbersome, weighing over 100 tonnes (220,000 lb) and riding on or in 15 vehicles. Each battalion had a personnel strength of more than 250, and after the launch decision a delay of from four to (usually) seven hours had to precede the actual firing command. This was largely occupied in preparing a launch site, surveying, setting up the guidance and getting the parts of the system dismounted and connected together. The result was often impressive: at a demonstration at White Sands (New Mexico) Proving Ground in July 1958 an improved **M2A1** impacted 14.6 m (48 ft) to the left and 3.6 m (12 ft) short of its target at a range of 50 km (31 miles). Several hundred rounds served with US Army battalions from 1954, two being based in Italy, while the British Army's 47th GW Regt, Royal Artillery, used Corporal in 1956-66. From 1962 onwards the US designation (M2A1) was **MGM-5B**.

Specification
Corporal

Type: tactical artillery missile

Propulsion: one 9072-kg (20,000-lb) thrust Ryan rocket engine burning RFNA (red fuming nitric acid) and aniline

Performance: speed at burn-out about 4281 km/h (2,660 mph); maximum range 113 or 138 km (70 or 86 miles) depending on warhead

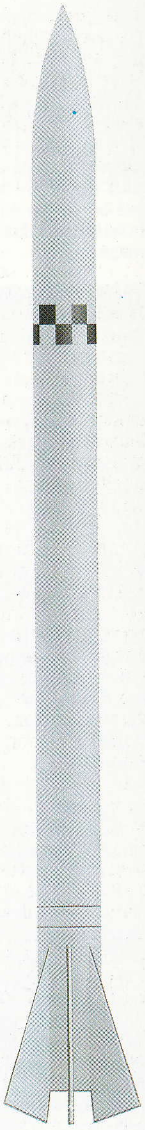
Weight: launch (typical) 5443 kg (12,000 lb)

Dimensions: length 14.02 m (46 ft 0 in); body diameter 0.76 m (2 ft 6 in); fin span 2.13 m (7 ft 0 in)

Warhead: 1500-kg (3,307-lb) HE or nuclear

Guidance: Gilfillan system based on launch azimuth, radar Doppler velocity measurement and launch-site computation of trajectory

Control: electrohydraulic power units driving refractory jet vanes and four aerodynamic control fins



Right: Developed from a research vehicle, the slender Corporal had a range of up to 139 km (86 miles). Given adequate preparation of the launch site the missile could be extremely accurate.

USA

Sperry Sergeant

As in any new technical field, early missiles had hardly been created before it could be seen that they were obsolete. This was certainly the case with the Corporal. Basic research and planning for the Corporal had been done by the Jet Propulsion Laboratory of the California Institute of Technology, which by 1955 had designed a second-generation system with a new missile, unjammable guidance and totally new ground equipment. In early 1956 JPL handed this **Sergeant** system over to Sperry Rand for production, with US Army designation **XM15**. The missile was shorter than the Corporal, had a Thiokol cast polysulphide solid rocket motor and self-contained inertial guidance. A firing battery travelled on three semi-trailers and a standard truck, which among other items carried sealed containers housing the motor, guidance section and conical warhead, as well as the four fins with powered controls. These had to be assembled under the girder forming the launch rail, after which the missile would be checked out by two truck-mounted test stations. The launcher would then be pointed exactly towards the target and the missile launched at 75° elevation. There was no provision for thrust cut-off, range being determined by opening airbrakes around the guidance section. By the time the first test under battlefield conditions took place in September 1961 the Sergeant, then about to be redesignated **MGM-29A**, could be seen to have become obsolete. A far better new-generation missile was the British Blue Water, but British political 'clout' was non-existent so the Blue Water was cancelled and the Sergeant deployed by the US and West German armies in 1962-78.

Specification
Sergeant

Type: tactical artillery missile

Propulsion: one Thiokol M53 solid-propellant rocket motor with a thrust of 24948 kg (55,000 lb)

Performance: burn-out speed 3701 km/h (2,300 mph); operational range 45 to 140 km (28 to 87 miles)

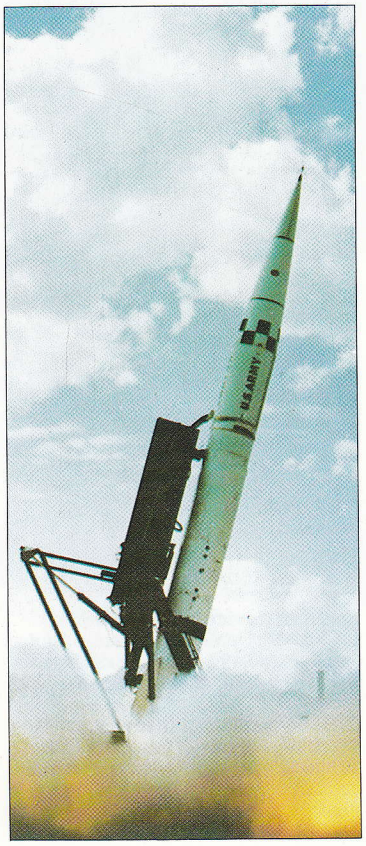
Weight: launch 4500 kg (9,920 lb)

Dimensions: length 19062 m (34 ft 10 in); body diameter 0.79 m (2 ft 7 in); fin span 1.80 m (5 ft 11 in)

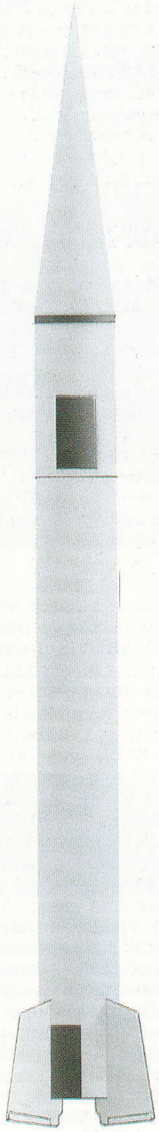
Warhead: nuclear up to 20 kilotons, chemical or conventional

Guidance: primitive inertial over precomputed trajectory

Control: four jet vanes, four aerodynamic fins and timed airbrake deployment



Test firing of Sergeant under battlefield conditions proved that even though ground handling equipment and the guidance systems were greatly improved over the Firestone Corporal, the pace of technological change had made the Sergeant obsolescent.

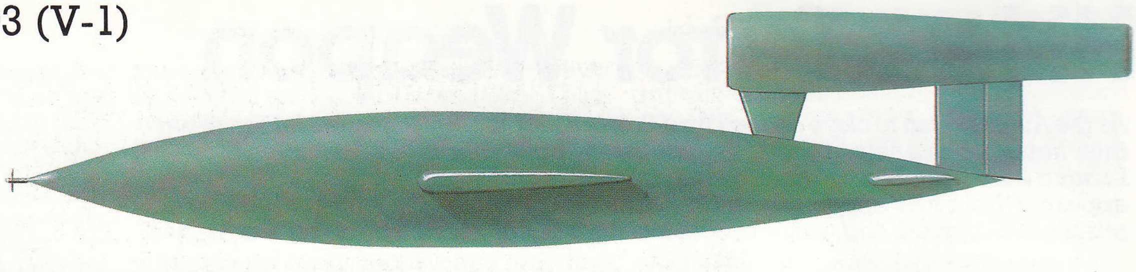


Smaller than the preceding Corporal, the Sergeant had a similar range. The warhead could be conventional explosive, chemical, or nuclear of up to 20 kiloton yield.

GERMANY

Fieseler Fi 103 (V-1)

The first aerial self-guided missile to be used in history, this cruise missile got its popular designation **V-1** from **Vergeltungswaffe-1** (reprisal weapon 1), though its true designation was **Fieseler Fi 103**. It was also given the cover designation **FZG 76** (anti-aircraft target 76). Its development started in 1942 when Generalfeldmarschall Milch authorized the Schmidt pulsejet, a novel form of jet engine, to be used to propel a cheaply produced 'flying bomb'. The first powered flight was on 24 December 1942, and after many delays the bombardment of London began on 13 June 1944. The V-1 was most erratic and imprecise, but London was an ideal target. The bomb was fired by a chemically powered piston driven along an inclined ramp. Hundreds of launch sites near the Channel were attacked by Allied aircraft, and gradually AA guns and fighters got the upper hand, and fortunately for the UK the assault never approached the planned 3,000 per day (the peak was 316 firings from 38 sites on 2 August 1944). Nobody in south east England will forget the loud throb of the approaching bombs, the sudden silence as the engine cut, and the wait of a few seconds for the tremendous explosion. Over 1,200 bombs were air-launched from Heinkel He 111H-22 bombers, and some 2,448 fell on Antwerp and Brussels in early 1945. Variants included long-range types with increased span and a wooden warhead case. Production exceeded 29,000, almost all from the vast slave-worked Mittelwerke near Nordhausen. The **Reichenberg IV** piloted version was flown but not used.



The Fieseler Fi 103 first flew on Christmas Eve 1942, and on 13 June 1944 became the first self-guided missile to be used in anger.

Specification

Fi 103 (standard)

Type: bombardment cruise missile launched from fixed sites (or air-launched)

Propulsion: one Argus-Schmidt 109-014 spring-valve pulsejet operating with frequency of about 47 hz to give a sea-level thrust of 300 kg (661 lb)

Performance: speed (early) about 599 km/h (372 mph) or (from late 1944) up to 800 km/h (497 mph); range (standard model) 240 km (149 miles) or (extended-range type) 320 km (199 miles)

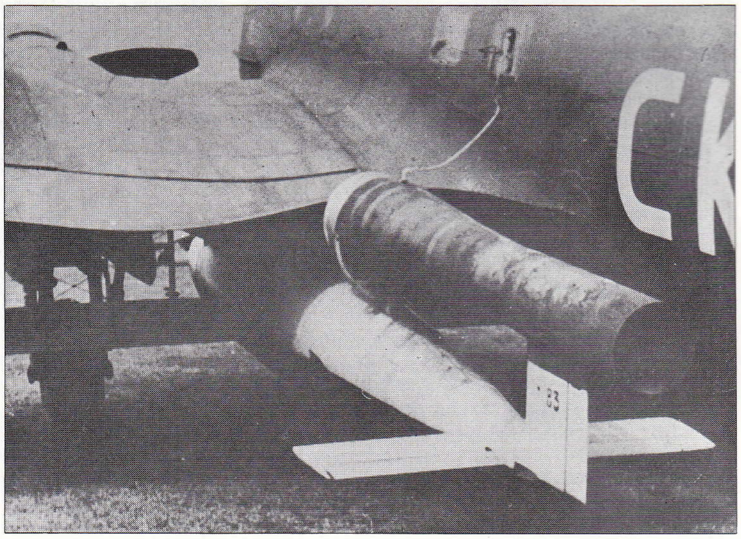
Weight: launch typically 2180 kg (4,806 lb)

Dimensions: span 5.30 m (17 ft 4.7 in) or (extended-range model) 5.72 m (18 ft 9.2 in); length 8.32 m (27 ft 3.6 in) or (short-nose version) 7.73 m (25 ft 4.3 in)

Warhead: 850-kg (1,874-lb) or (long-range model) 454-kg (1,000-lb) conventional (RDX mixtures)

Guidance: an autopilot held course of launch ramp, and an air-log windmill measured distance and at appropriate point cut off fuel and commanded dive

Control: elevators and rudder only



While the majority of the flying-bombs were launched from inclined ramps, more than 1,200 were dropped from Heinkel He 111H-22 bombers, foreshadowing the air-launched cruise missile of today.

GERMANY

Peenemünde A4 (V-2)

The **Peenemünde A4**, a superb long-range rocket, was unquestionably the greatest single thrust into the unknown in the history of technology, and the development programme resulted in a weapon against which there was no defence. At the same time it has been argued that it did nothing to stave off the defeat of Nazi Germany, and that possibly the large resources committed to it might have been put to better use. Work on liquid-propellant rockets began in Germany by enthusiasts at the VfR (Society for Spaceflight) in the 1920s, one of the leading young engineers being Wernher von Braun. By 1934 the work had achieved official status with funds from the army and a research establishment on the range at Kummersdorf. Hauptmann (later General) Walter Dornberger headed the army team, which in 1937 moved to remote Peenemünde and began testing ever-bigger rockets. At last the mighty A4 rocket design was completed, in late 1941, and the first A4 was fired on 13 June 1942; it exploded. The second A4, launched on 16 August, was the first missile to fly faster than sound. The third, fired on 3 October, flew under full power for a minute, reaching 190 km (118 miles). Suddenly Hitler ordered the rocket by the thousand as the **V-2** (**Vergeltungswaffe-2**, reprisal weapon 2). A stupendous production programme got under way in the vast Mittelwerke mines, and at last (as related in this issue) the army firing troops were ready. On 6 September 1944 two rockets were fired (unsuccessfully) against Paris. On 8 September the real bombardment began, against London. For a while the British government, which had advised Prime Minister Churchill that such a rocket could not be built, and that the RAF should stop wasting time looking for it, told the public the explosions were caused by faulty gas mains. Within days the truth had to be admitted, but Londoners just got on with winning the war. They got quite used to hearing a sudden deafening explosion, followed by the long diminishing rumble, just like thunder, caused by the supersonic plunge of the missile through the sky. In 1945 many were fired against Antwerp. Nearly 5,000 of the weapons were launched (of over 10,000 built), of which 4,320 hit Allied territory.

Specification

A4

Type: long-range ballistic missile

Propulsion: single rocket chamber fed by 544.4-kW (730-hp) pumps with liquid oxygen and alcohol for a sea-level thrust of about 26000 kg (57,330 lb)

Performance: burn-out/cut-off speed and impact speed both about 5790 km/h (3,600 mph); maximum range 320 km (199 miles)

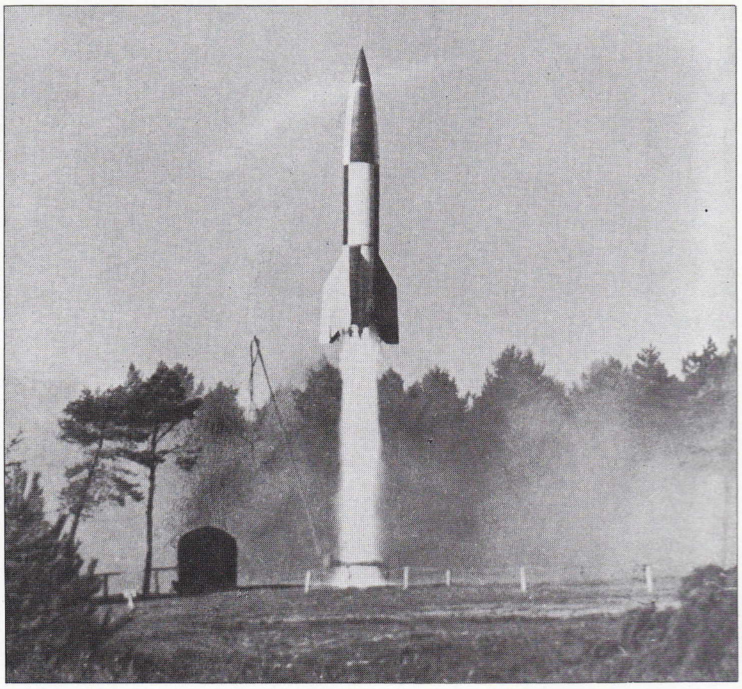
Weight: lift-off 12870 kg (28,373 lb)

Dimensions: length 14.05 m (46 ft 1.1 in); diameter 1.68 m (5 ft 6.1 in); fin span 3.57 m (11 ft 8.6 in)

Warhead: 910-kg (2,006-lb) conventional (amatol mix)

Guidance: inertial, with stable platform, accelerometers and timed fuel cut-off

Control: jet deflector vanes and aerodynamic control fins



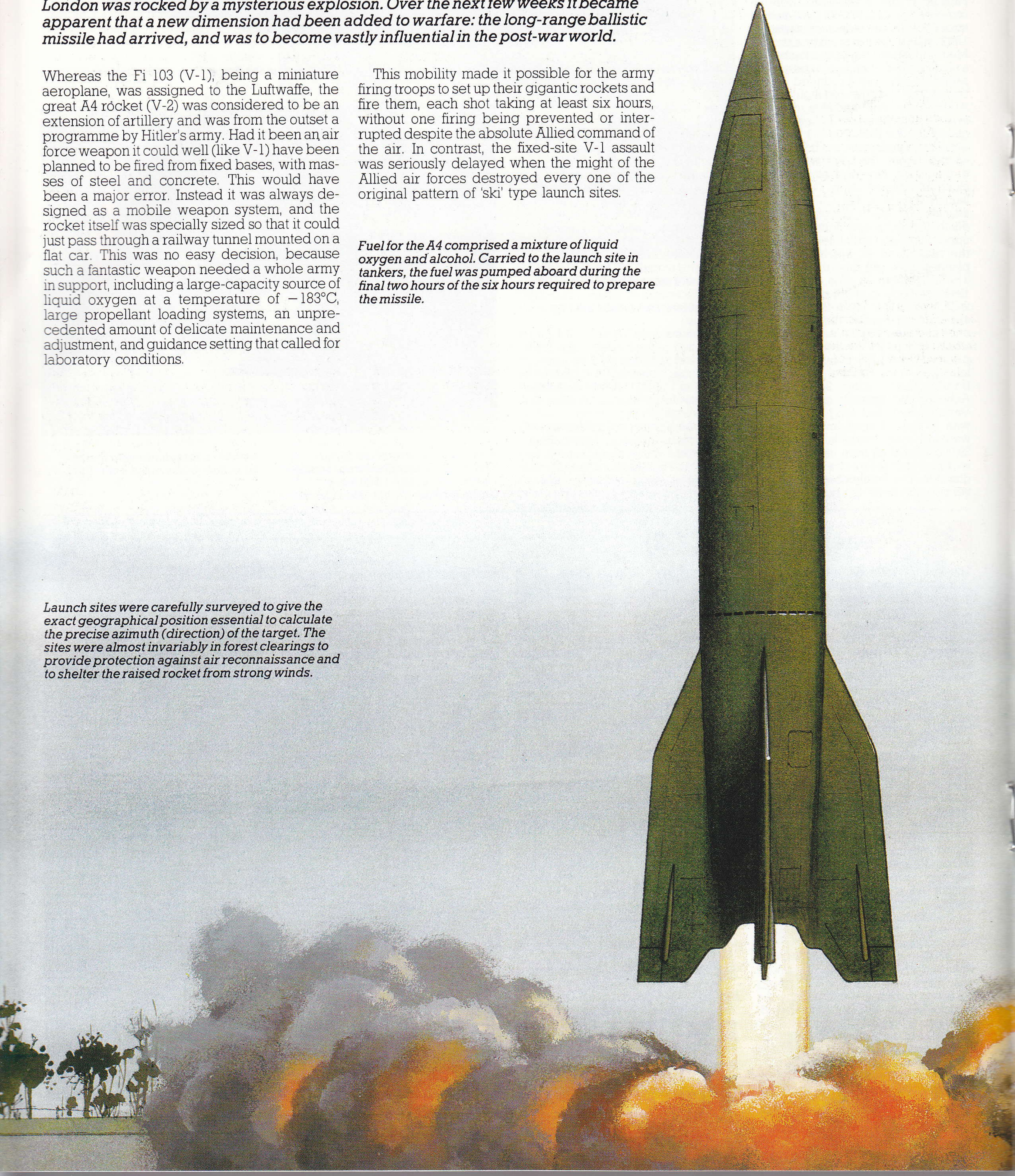
A captured A4 rocket is test fired by British scientists from a site near Cuxhaven late in 1945. Commonly called the V-2, the A4 was undoubtedly one of the most significant advances in weapons technology ever achieved.

Hitler's Terror Weapon

As the Allies began to close on the Third Reich, Hitler and his followers began to pin their hopes upon a new 'wonder weapon'; on 8 September 1944 Chiswick in West London was rocked by a mysterious explosion. Over the next few weeks it became apparent that a new dimension had been added to warfare: the long-range ballistic missile had arrived, and was to become vastly influential in the post-war world.

Whereas the Fi 103 (V-1), being a miniature aeroplane, was assigned to the Luftwaffe, the great A4 rocket (V-2) was considered to be an extension of artillery and was from the outset a programme by Hitler's army. Had it been an air force weapon it could well (like V-1) have been planned to be fired from fixed bases, with masses of steel and concrete. This would have been a major error. Instead it was always designed as a mobile weapon system, and the rocket itself was specially sized so that it could just pass through a railway tunnel mounted on a flat car. This was no easy decision, because such a fantastic weapon needed a whole army in support, including a large-capacity source of liquid oxygen at a temperature of −183°C, large propellant loading systems, an unprecedented amount of delicate maintenance and adjustment, and guidance setting that called for laboratory conditions.

This mobility made it possible for the army firing troops to set up their gigantic rockets and fire them, each shot taking at least six hours, without one firing being prevented or interrupted despite the absolute Allied command of the air. In contrast, the fixed-site V-1 assault was seriously delayed when the might of the Allied air forces destroyed every one of the original pattern of 'ski' type launch sites.



Fuel for the A4 comprised a mixture of liquid oxygen and alcohol. Carried to the launch site in tankers, the fuel was pumped aboard during the final two hours of the six hours required to prepare the missile.

Launch sites were carefully surveyed to give the exact geographical position essential to calculate the precise azimuth (direction) of the target. The sites were almost invariably in forest clearings to provide protection against air reconnaissance and to shelter the raised rocket from strong winds.

Pilot production of the A4 missile began in a new factory just south of the Peenemünde test establishment in early 1943. In August 1943 RAF Bomber Command badly damaged this plant, and the task of delivering over 1,000 rockets per month was transferred to the colossal slave mines at Nordhausen, where nearly 30,000 slave workers died in 19 months. The great rocket became available in quantity by November 1943, by which time the first technical instructors of the initial army unit, 836 Artillerie Abteilung, had completed their own courses at Peenemünde. They in turn set up an army A4 rocket school in Pomerania, not far from Peenemünde, at Köslin. By January 1944 the first firing troops were ready with their rockets on a former Polish army reservation near Blizna. About 600 A4s were fired in troop training between January 1944 and February 1945, almost all of them on the Blizna range. One of the early shots fell in a Polish forest and did not explode. It was reached by courageous Poles who, via the secret resistance network, sent word to London. In 36 hours an RAF Douglas Dakota arrived by night and collected vital parts. Altogether the Dakota made three perilous journeys to Poland, bringing back every removable part of the rocket.

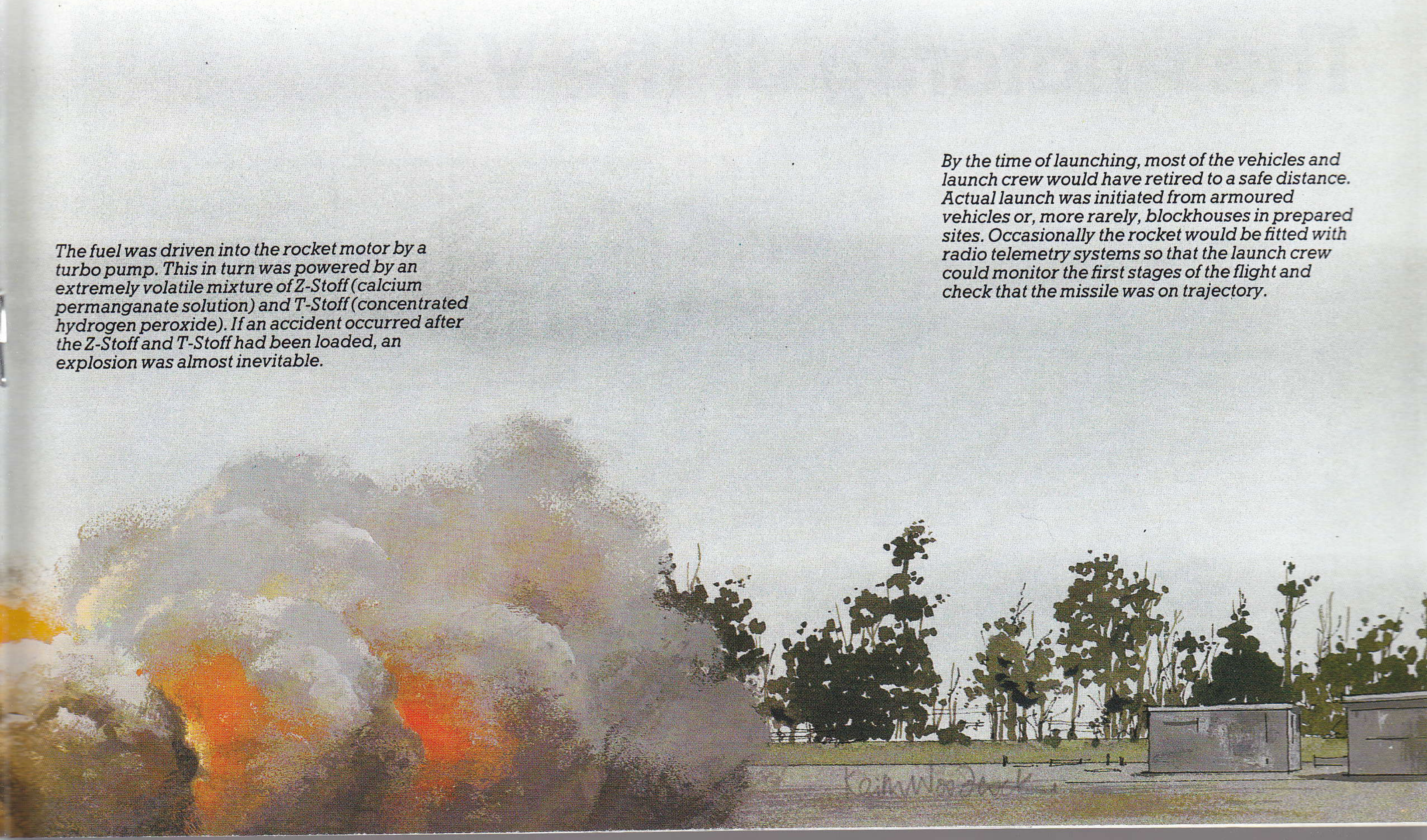
Transport

Though test firings had involved huge gantries positioned over concrete pads with massive installations for the propellants and many other services, the field troop had to carry everything with them. Transport of rockets and some other parts over long distances was usually on rail flat cars or in box cars, and by December 1944 actual firings were being made from the same rail flat cars. At first, however, the firing troop carried with them a launch platform in the form of a welded steel circular table standing just over 2 m (6 ft 7 in) high and 3 m (10 ft) in diameter, and strong enough to support the fully loaded missile even in a blustery gale. Centred on the base of this launcher was a conical steel flame deflector which, at launch, diverted the intensely hot flame sideways. Despite the treatment received, these platforms were massive enough to be reusable, and some survived a dozen launchings.

In its initial form the A4 rocket system comprised 28 or 30 vehicles, which drove in convoy (normally by night) along highways and then turned off to traverse an easy stretch of fairly even and firm ground to reach the pre-surveyed launch site. From the start it was accepted that the rocket was too big to hide or to camouflage, and there was little attempt to prevent detection from the air. Early production A4s were painted mainly dark green, though from August 1944 Mittelwerke rockets were camouflaged in pale green/grey patterns. They were normally carried on a *Meillerwagen*, a long steel lattice frame riding on three sets of pneumatic tyres behind a large tractor vehicle. This *Meillerwagen* gripped the rocket in calipers, holding it firmly against soft pads. By October 1944 it was common for a single firing unit to travel by night with as many as five rockets, all supported by the same service vehicles though, of course, needing five loads of alcohol and rapidly evaporating liquid oxygen. It goes without saying that the personnel were under most rigorous discipline, doing everything totally by numbers 'according to the book'.

Vehicles were divided into 'soft', which could clear the site before launch, and 'hard' which were needed near the rocket throughout the launch. The latter were all armoured, several (including the vital launch control centre) being based on armoured cars of the SdKfz 231 or 238 types, with six or eight wheels or, increasingly, on halftrack suspension for greater towing power. There was a need for plenty of pulling power, for the rockets on their *Meillerwagen* vehicles, for the protected van with warheads, for the guidance station vehicles, for nine types of workshop, and above all for the propellant tanks. Experimental troops even carried their own liquid-oxygen production plant. A mobile crane was needed to offer up the warhead section, weighing about 975 kg (2,150 lb), of which a remarkable 93 per cent was explosive. The fairly weak 60/40 Amatol filling was the lesser of two evils. More powerful explosive such as Trialen invariably detonated during re-entry back into the atmosphere, when the nosecone was heated to a bright cherry red by friction with the air. Despite

The A4 was guided relatively simply, being aligned in the direction of the target. Gyros and accelerometers were fitted to gently tip the rocket into the required trajectory and to cut the main engine at the precise velocity to ensure that its ballistic path would carry it to the target.



By the time of launching, most of the vehicles and launch crew would have retired to a safe distance. Actual launch was initiated from armoured vehicles or, more rarely, blockhouses in prepared sites. Occasionally the rocket would be fitted with radio telemetry systems so that the launch crew could monitor the first stages of the flight and check that the missile was on trajectory.

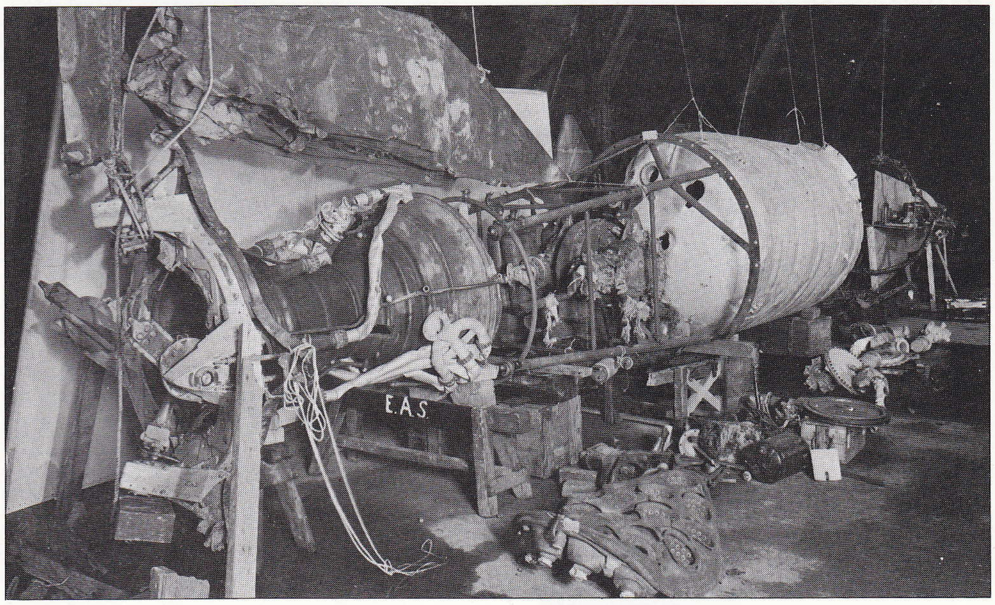
The fuel was driven into the rocket motor by a turbo pump. This in turn was powered by an extremely volatile mixture of Z-Stoff (calcium permanganate solution) and T-Stoff (concentrated hydrogen peroxide). If an accident occurred after the Z-Stoff and T-Stoff had been loaded, an explosion was almost inevitable.

thick glass wool insulation, which was also needed around the alcohol and liquid oxygen tanks, many rockets still exploded prematurely high above the earth, though the launch troops knew nothing of this.

The transporter incorporated a giant hydraulic ram, usually powered from an external source, which slowly raised the complete cradle and missile vertically onto the launcher. The latter had to be towed to the selected spot, the wheels removed, and the platform levelled with spirit levels. Once it was bearing the rocket's weight the platform was carefully watched for subsidence as the *Meillerwagen*'s restraining calipers were slowly released. The transporter then cleared the site and subsequent access was by a mobile ladder 14 m (46 ft) long, or roughly twice the height of an average house. Soon after elevation the loading of 4173 kg (9,200 lb) of ethyl alcohol was started. Personnel at the top of the ladder would attend to the gyros and accelerometers in the guidance compartment, and also charge the main nitrogen bottles. At this stage it was necessary to rotate the upper table of the launch platform to get the missile exactly aligned with the azimuth (direction) of the target, because there was no provision for changing direction after launch. All that the guidance system did was control the missile as it gently tipped over towards the target and finally cut off main-engine propulsion at exactly the right velocity (this was done in a way similar to modern inertial systems, by measuring the varying acceleration of the missile and measuring the time).

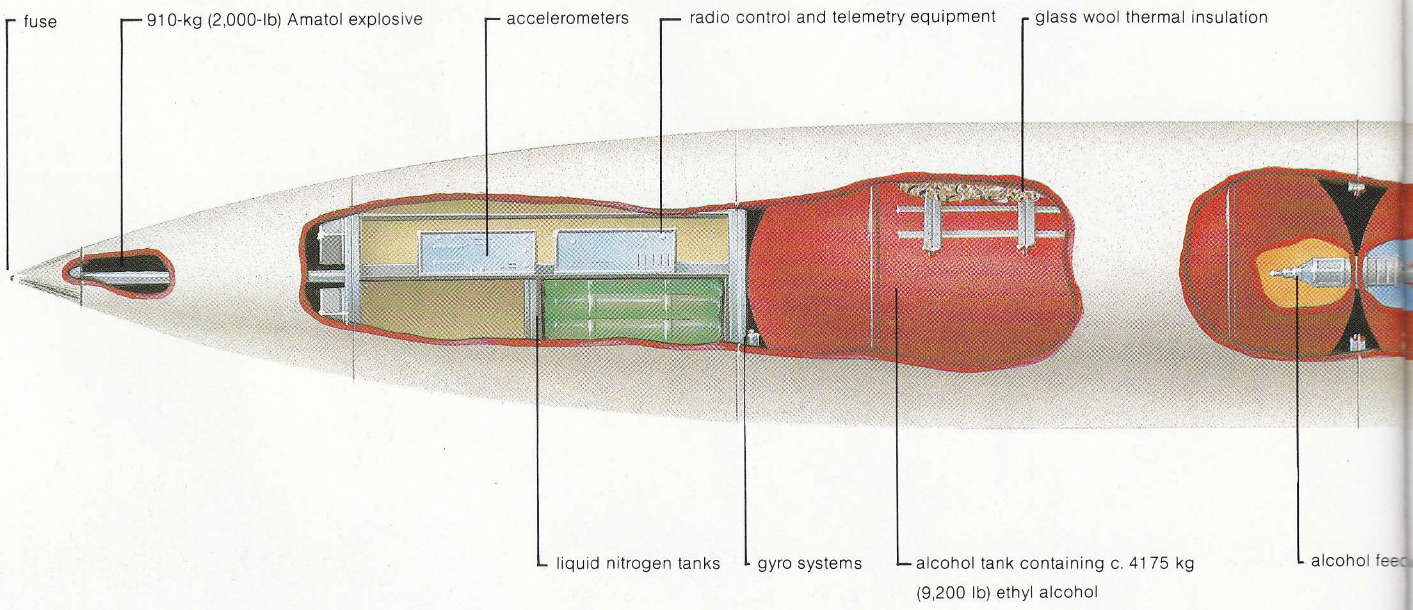
The launch troop had to work their way through two substantial manuals of procedures, which in all took a minimum of six hours. There were over 180 checks and measures to be made of electrical items alone, the absolute cleanliness of the peroxide lines had to be established, and the correct operation of the four graphite jet deflector vanes and four outboard aerodynamic rudders had to be verified. In the final two hours the intensely cold liquid oxygen was carefully pumped aboard, the quantity being an awesome 5533 kg (12,198 lb). Unlike the situation with such later missiles as the Atlas and Jupiter, this did not result in frost covering the outer skin because of the thick lagging inside. Last of all, and with the strictest adherence to procedures, the fluids needed to drive the turbopump were loaded: Z-Stoff (calcium permanganate solution) and 172 kg (379 lb) of T-Stoff (concentrated hydrogen peroxide). Once these were aboard the A4 was regarded with the greatest respect. Nobody liked it if the day was windy, because a toppled-over missile invariably went up in a fireball even if the simple electric-contact fuse on the tip of the nose failed to hit the ground.

In the last minutes the radio telemetry (often carried to log the achieved trajectory) was activated, linked with four slim aft-facing rod aerials at the trailing edges of the giant fins. By this time everyone would be far from the rock-

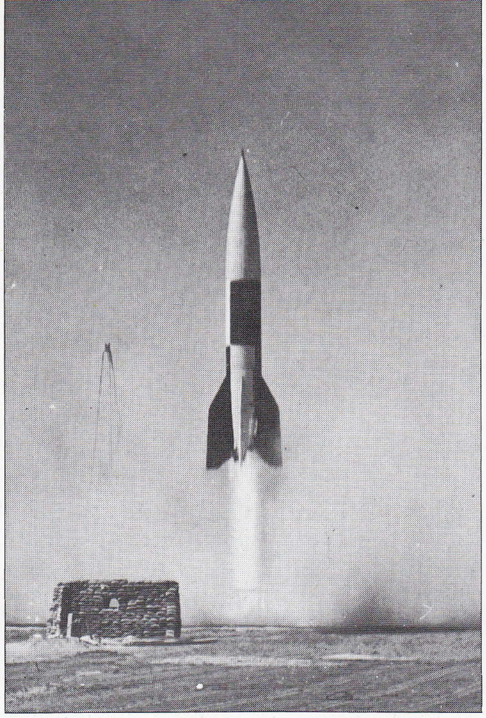


In 1944, the Polish Resistance managed to smuggle parts of a crashed V-2 to London, a C-47 Dakota making three clandestine trips to collect the pieces. Together with the remains of the first missile to hit London, the parts enabled the RAE at Farnborough to reconstruct the missile.

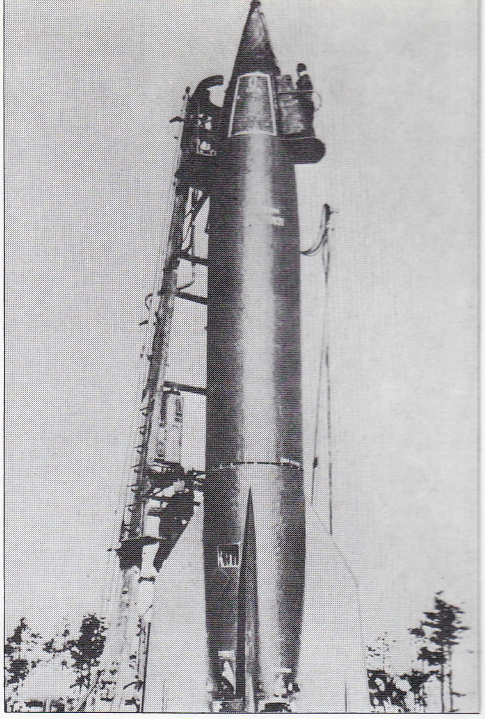
The Anatomy of the V-2


fuse
910-kg (2,000-lb) Amatol explosive
accelerometers
radio control and telemetry equipment
glass wool thermal insulation
liquid nitrogen tanks
gyro systems
alcohol tank containing c. 4175 kg (9,200 lb) ethyl alcohol
alcohol fee

An operational A4 missile is seen on its transporter shortly after elevation and prior to test firing on test pad 7 at the Peenemünde test establishment.



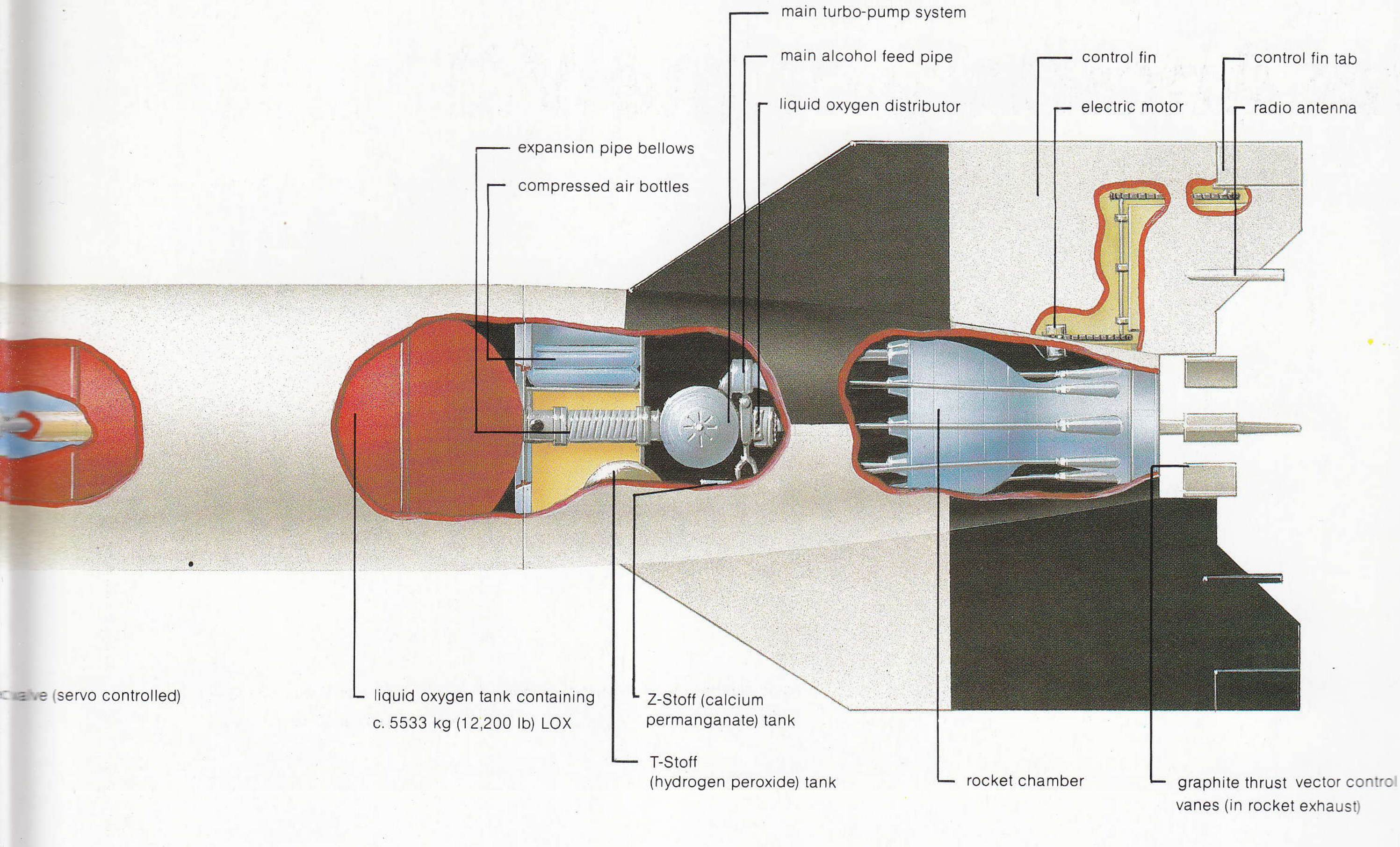
A captured A4 is launched in New Mexico in May 1946. German technology and German engineers played a vital part in early missile work in both the USA and the USSR.



An A4 is prepared for launching. The launch crew at the nose are preparing the gyros and accelerometers which will provide attitude and thrust cut-off control during flight.

et, except for the launch control vehicle which remained linked by two heavy cables. Launch was by manual procedures, with verification between steps. Three sets of safety links and valves had to be activated before the actual firing, which began by opening the nitrogen feed valve and then the master valves for peroxide and permanganate. These mixed in a reaction chamber to generate high-pressure superheated steam to drive the 544.4-kW (730-hp) turbopump. As soon as this started turning it began feeding the main propellants, the liquid oxygen passing through a distributor leading to the rings of injectors in the head of the combustion chamber, and the alcohol reaching the same injectors via the double wall of the nozzle in order to provide essential cooling. Ignition of the main propellants was electrical, by an exploding bridgewire. Acceleration of the turbopump to full speed took less than two seconds, by which time the main engine should (in theory) be putting out full thrust. This would raise the missile off the launcher, its stability being assured by the graphite vanes in the rocket jet.

Within two or three seconds the great rocket would rise above the surrounding trees, which were always present to provide some protection against the wind and air reconnaissance. At this point the rocket would be seen by people in surrounding villages and probably by Allied pilots, but though several Allied fighters tried to chase rising A4 rockets not one was ever shot down. One, in fact, climbed vertically just as a Spitfire Mk XIV passed overhead in a tight turn, and disappeared into cloud before the fighter could get near it. As it climbed away it was slowly tilted over by its guidance to an angle of 45° or even 40°, depending on the target distance. Then, about 60-70 seconds from lift-off, the propulsion was cut off, the trajectory having been established.


main turbo-pump system
main alcohol feed pipe
liquid oxygen distributor
control fin
electric motor
control fin tab
radio antenna
expansion pipe bellows
compressed air bottles
valve (servo controlled)
liquid oxygen tank containing c. 5533 kg (12,200 lb) LOX
Z-Stoff (calcium permanganate) tank
T-Stoff (hydrogen peroxide) tank
rocket chamber
graphite thrust vector control vanes (in rocket exhaust)

Dawn of the ICBM

The revelation that was German rocket technology led both the superpowers to attempt the extremely ambitious feat of developing a missile capable of carrying a thermonuclear warhead over intercontinental distances. From the first, however, very different approaches were apparent.

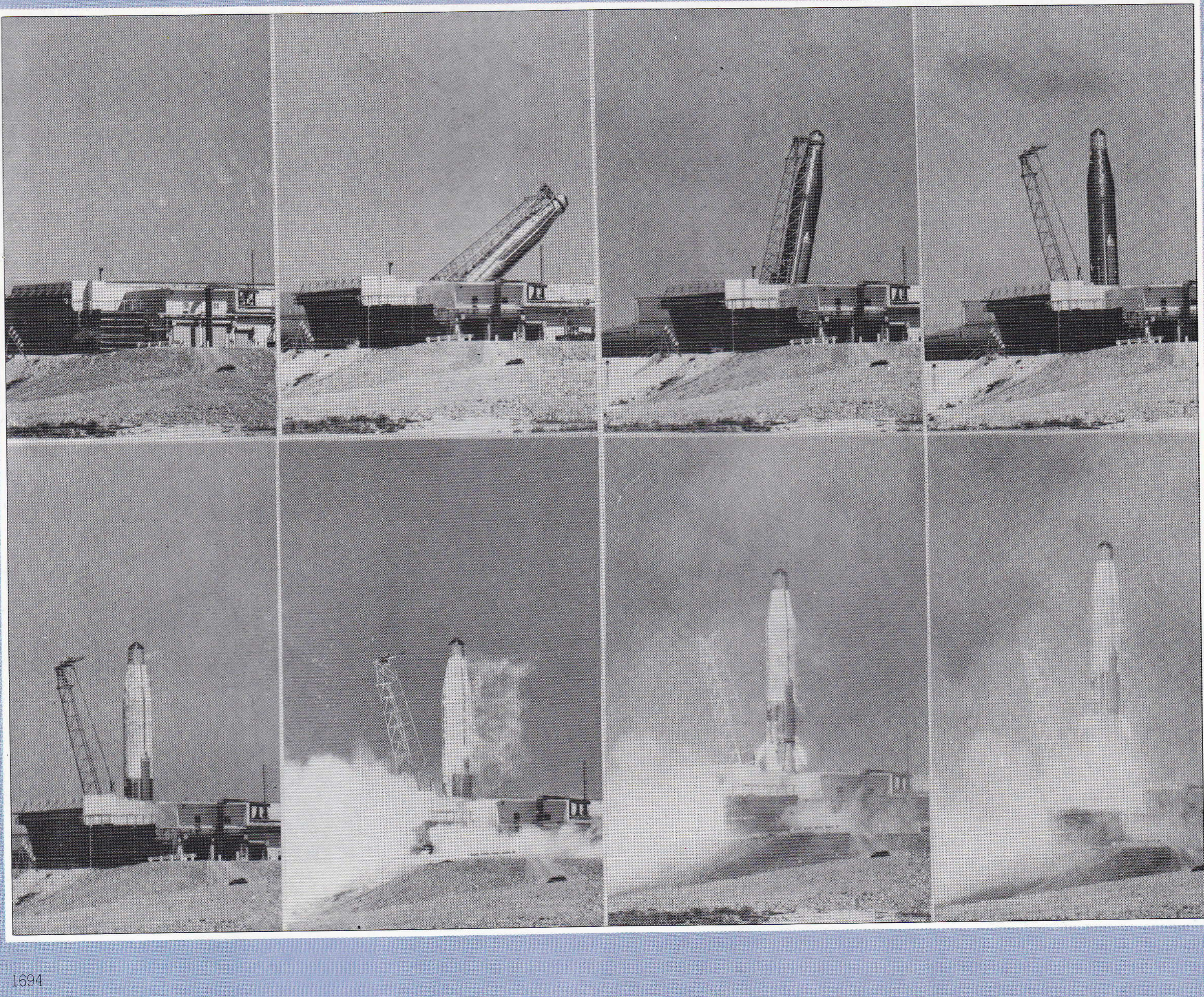
Though the emergence in 1944 of the German V-2 as a practical weapon jolted many observers (scientists and engineers included) into an age of wholly new possibilities, there were still many who lacked the ability to look ahead. Of course, not many nations possessed the resources and motivation to take an active interest in big rockets, ICBMs (intercontinental ballistic missiles) and spaceflight. Germany alone had experience, but her rocket teams were dispersed among the Allies. The UK had the resources but totally lacked motivation. Only the USA and Soviet Union showed real interest, spurred on by mutual competition and mutual distrust.

In 1947 the USAAF awarded a contract to Convair to study the ICBM. The San Diego company designed the MX-774 which introduced three totally new features. The liquid propellants for the rocket engine were contained in tanks made of stainless-steel sheet rolled so thin (almost like foil) that the interior had to be pressurized like a balloon to stabilize its shape. In the V-2 the jet from the rocket engine could be deflected by pivoting four graphite vanes projecting into the flame; Convair saw that it would be more efficient if the chamber itself could be gimballed, mounted on two sets of pivots at 90°, so that it could direct the whole jet in any desired direction and without loss of thrust. Finally, the nosecone was arranged to separate after cut-off of propulsion, to increase accuracy.

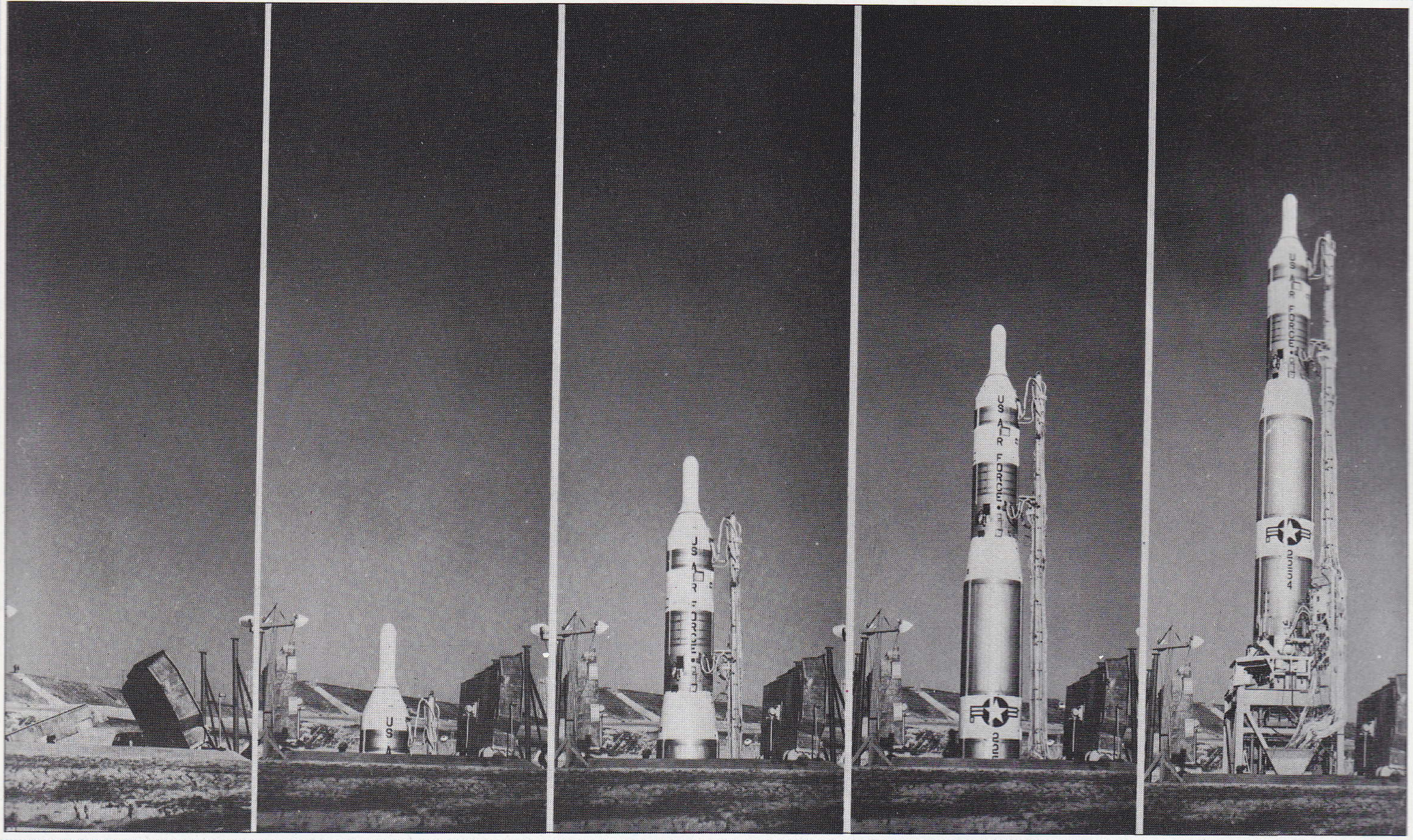
Though intrigued by these developments, the prevailing opinion was that the ICBM was incapable of being built, so the USAF, in one of its first acts as an independent service, cancelled the contract. Convair spent its own funds testing the MX-774 vehicles.

Meanwhile, in the Soviet Union the invariable philosophy is 'Plod ahead unceasingly, doing whatever becomes possible as soon as it becomes possible.' More than any other country the Soviet Union investigates problems mathematically and, if the answers appear to make sense, proceeds with the development. As early as 1947 Soviet workers, assisted by German prisoners, had on paper worked out how to design not only an ICBM but also a satellite launcher using existing A4 technology. Moreover, under Academician Sergei P. Korolev, they came up with the answer that the ICBM could be created without using a two-stage vehicle. By firing all engines on the ground, reliability was clearly increased.

Later in 1947 design began of the RD-100 rocket engine at the GDL (gas dynamics laboratory) in Leningrad. This was slightly more advanced than the A4 engine, used the same propellants fed by a turbopump driven by the same permanganate/peroxide mix, and on test in May 1948 gave a thrust of 27525 kg (60,682 lb). In 1949 this led to the RD-101, with various improvements and higher thrust, and in 1950 to the RD-103, of 44870-kg (98,921-lb) thrust. Both engines were mass-produced, giving confidence for Korolev, with V.P. Glushko, to go ahead in January 1954 with the design of the mighty R-7 ICBM, the first in the world. A critic might say it was a 'brute force and ignor-



This sequence of photographs was taken over a 15-minute period at Vandenberg AFB, and shows the process of erecting an Atlas missile, fuelling and launching it. Thus the USA would need at least 15 minutes' warning of a nuclear attack.



By the time Titan I entered service, missiles were stored upright in hardened silos. However, the missiles still had to be fuelled and raised above ground for firing, a difficulty which Titan II was to overcome.

ance' creation, and certainly it bore more kinship with the spaceships of pre-war fiction than with practical modern weapons. As described elsewhere, the R-7 (called SS-6 'Sapwood' by NATO) is lifted off the ground by 32 rocket engines firing simultaneously!

As described in the entry for the SS-6, the 20 main engines of the R-7 missile were individually more powerful than any rocket engines previously built, with sea-level thrust from 77000 to 85000 kg (169,756 to 187,393 lb). The fact that so many were needed is explained by the sheer difficulty of flying the ICBM mission, over a range of some 10000 km (6,214 miles) with the ponderous warheads needed in 1954 to accommodate a thermonuclear 'H-bomb' device, which at that time by itself weighed some 7000 kg (15,432 lb). The R-7 vehicle featured a central core, with four main engines, surrounded by four jettisonable booster packages, each as big as a typical passenger airliner of the day, and each with its own quartet of engines. Vehicle control and final trimming of velocity was accomplished by 12 swivelling vernier engines. However much one might feel the R-7 an uninspired creation, one must marvel at the sheer money, effort and resources expended in order not only to build it but also to create its gigantic launch centres, the first of which (and possibly the only one) was at Baikonur, later a cosmodrome for space launches. Here, near the old city of Tyuratam, a launch complex 137 km by 89 km (85 miles by 55 miles) includes the stupendous hollowed-out launch complex (looking like a cross between a giant open-cast mine and Clapham Junction) from where R-7 made a 6500-km (4,039-mile) flight 'into the target area' on 21 August 1957. Previously, from 1951 to 1953, Soviet scientists had announced the possibility of orbiting Earth satellites; nobody seemed to show interest. But on 4 October 1957 the monster R-7 took off from Baikonur and placed *Sputnik 1* in orbit. To the amazement of the Americans, the space age had been brought in by the Soviet Union!

Subsequently, the nonstop development of Soviet ICBMs led to far more efficient missiles of terrifying size and power, and thousands today are at readiness. In terms of 'throw weight' the West has been far outpaced, because it lacks money to compete. This occurred despite what was in the 1950s superior ICBM technology in the USA. As described in this issue, once the USAF got the message that an ICBM was possible, it moved rapidly and Convair took only a few months to pick up the MX-774 concept and develop it into the much bigger SM-65 Atlas. Yet by comparison with the R-7, the Atlas was a tiddler. Instead of 32 engines it had three, none as big as the main R-7 engines. Yet it was still a missile big enough to pose severe deployment problems, and it is historically interesting that, though in its early years Atlas and other ICBMs were called 'the ultimate weapon', it does not seem to have occurred to anyone that they were self-cancelling. The combination of long range, warhead yield, accuracy and relatively brief flight time was such that any fixed object on our planet could henceforth be wiped off the map, unless it was hardened (protected against a nuclear explosion) to an unprecedented degree.

In fact, a far better way to make an ICBM survivable is to make it mobile. One of the best methods is surely to fit the whole system into what looks like just another freight train, as was originally proposed for the USAF's SM-80 Minuteman (which came two generations after the Atlas, with the SM-68 Titan in between). Such deployment was impossible with the Atlas, because physical size prevented it. There was no special problem in testing this ICBM at Cape Canaveral, where after two catastrophic explosions an Atlas made a successful flight on 17 December 1957. But deploying it in numbers with Strategic Air Command was complicated by the inability to get it right first time. The first SAC Atlas squadron had its missiles in soft above-ground buildings with end-sliding roofs. The next kept its missiles in above-ground buildings with split roofs opening sideways, thus saving a minute or two in the all-important 'reaction time'. The next had widely scattered individual missile buildings recessed into the ground, giving better protection. Then came a squadron with hardened microwave communications, after which came a dramatic improvement with missiles deep below ground in concrete silos.

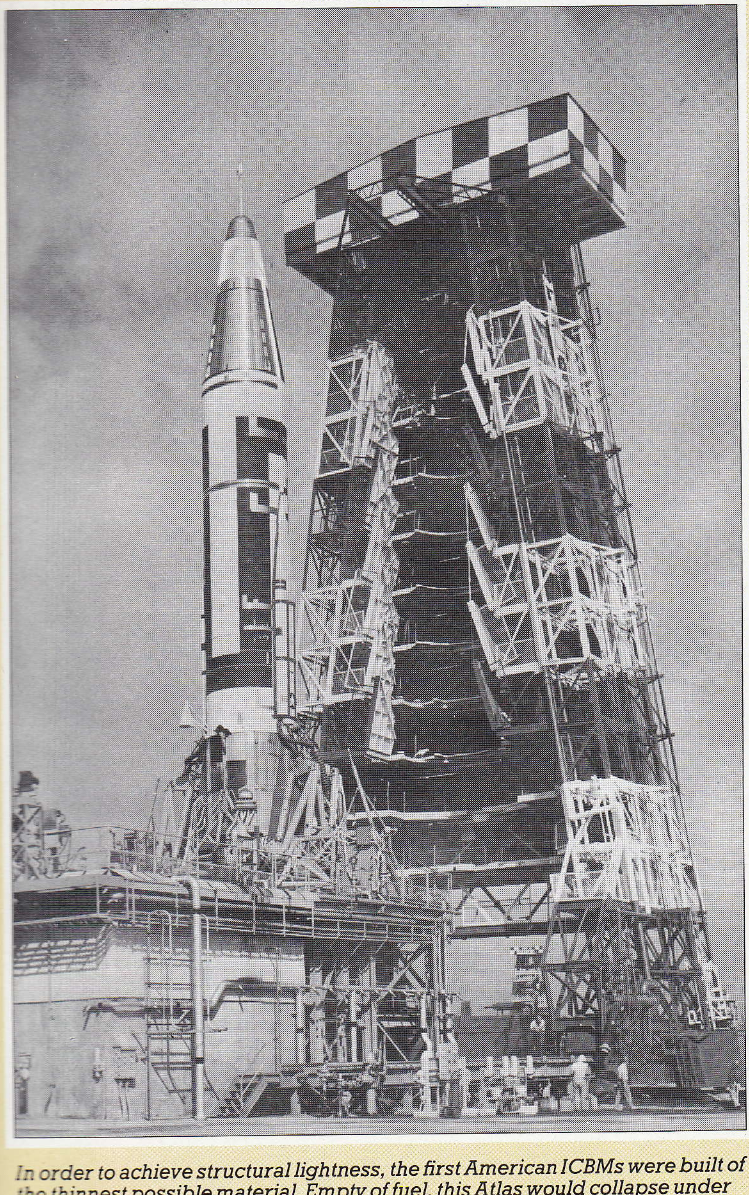
There was still a long way to go. The Atlases still had to be hoisted to the surface, and the liquid oxygen could not be loaded until an order to fire had been received. The missile was basically inefficient in having all engines ignited before lift-off; tandem stages are better. Later missiles introduced solid-propellant rocket motors, with many advantages, and miniaturized inertial guidance of pinpoint accuracy. The latest Soviet ICBMs have the 'cold' launch method, in which they are blown out of a deep silo by the silo's own gun-like system, the first stage motor being started well above the ground.

Wings or Rockets: the strategic choice

From the start it was clear that military planners had two options when considering strategic missiles. Cruise missiles – pilotless aircraft – were relatively cheap and could be built in some numbers, but were vulnerable to interception. The ballistic missile was more expensive and challenging, but had the advantage of invulnerability to interception.

The earliest war rockets (Chinese, Indian and British, in that order, from the 12th century onwards) were simple firework-like devices. In theory they followed the same kind of ballistic trajectory as a cannonball, though there were complicating factors. As late as World War II rockets were erratic. Manufacturing imperfections, which were difficult to eradicate, caused the thrust vector to vary unpredictably, while at high speeds the aerodynamic forces on the body become considerable, often giving destabilizing or lateral forces sometimes resembling the lateral thrust of a fast-spinning golf or tennis ball. All this added up to inaccuracy.

In World War I there were surprisingly few ballistic rockets, but plenty of a new species: pilotless miniature aeroplanes. Today we call this species cruise missiles. Compared with the ballistic rocket these generally fly much more slowly, and often at lower altitudes, but carry heavier warheads (or other payloads, such as reconnaissance sensors) and offer possibilities for very accurate guidance systems. At first, however, the guidance was the difficult part of all missiles. The underlying technology was almost non-existent.



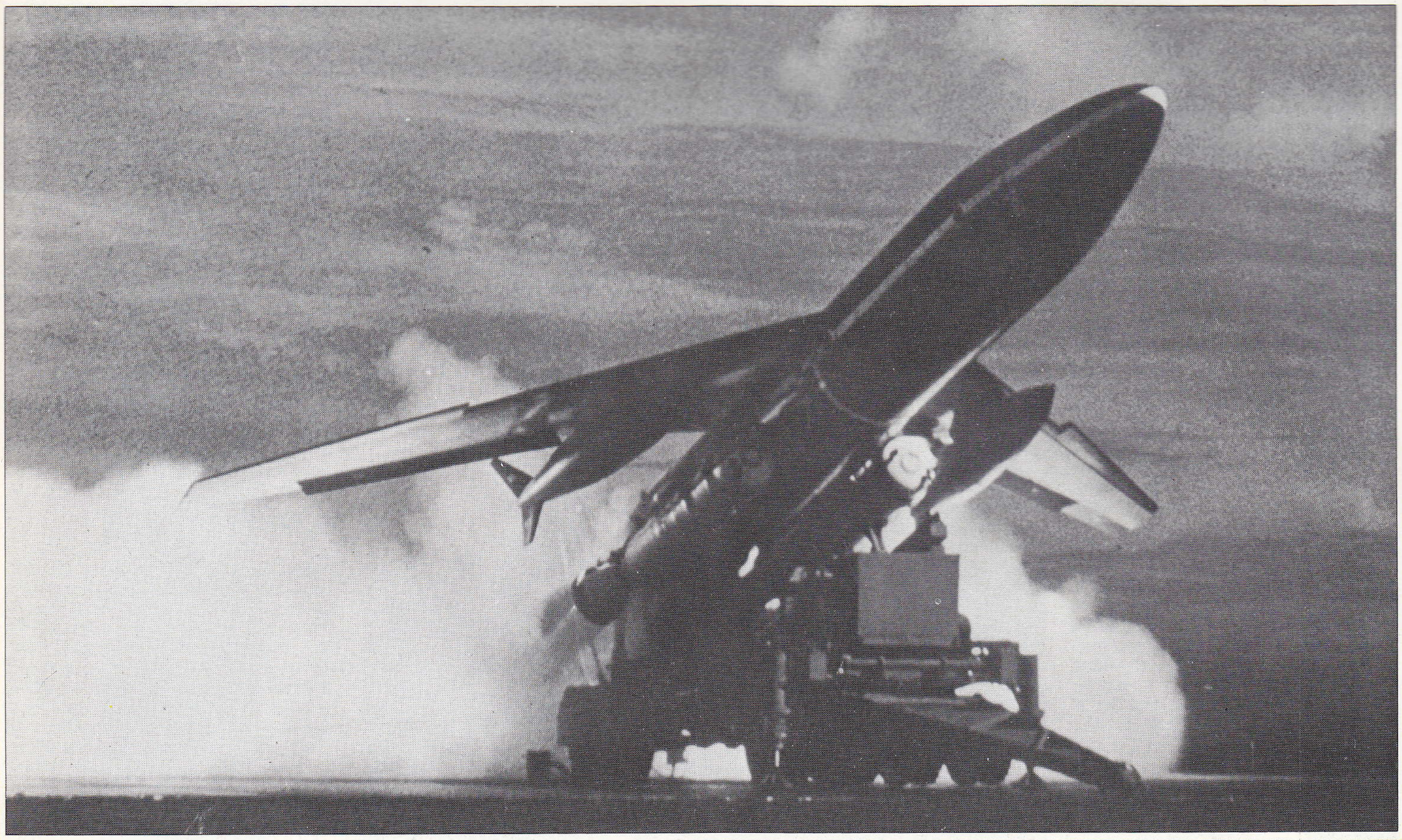
In order to achieve structural lightness, the first American ICBMs were built of the thinnest possible material. Empty of fuel, this Atlas would collapse under its own weight unless pressurized like a giant aluminium balloon.

Ballistic missiles stretched the limits of possibility, and mistakes could have disastrous consequences. Any explosions involving the enormous quantities of liquid oxygen required for ICBMs were certainly spectacular, as shown by this attempted Titan launch from Patrick AFB, Florida, in November 1959.

Today the situation is very different. Both species of missile are of the greatest importance. Both can carry devastating warheads over intercontinental distances, and with great accuracy. In general, today's cruise missile tends to be much smaller, and probably cheaper, than the corresponding ICBM (intercontinental ballistic missile). In turn this makes it easier to launch from an aircraft or an all-terrain land vehicle. Such mobile deployment is now essential if any so-called deterrent force is going to survive a pre-emptive strike by the other side, which today can eliminate anything whose location is accurately known. Yet the continued miniaturization of thermonuclear warheads, penetration aids (or penaids, designed to confuse and dilute the defences) and guidance systems has reduced the size of practical ICBMs to the point where these too can be fired from mobile cross-country launchers.

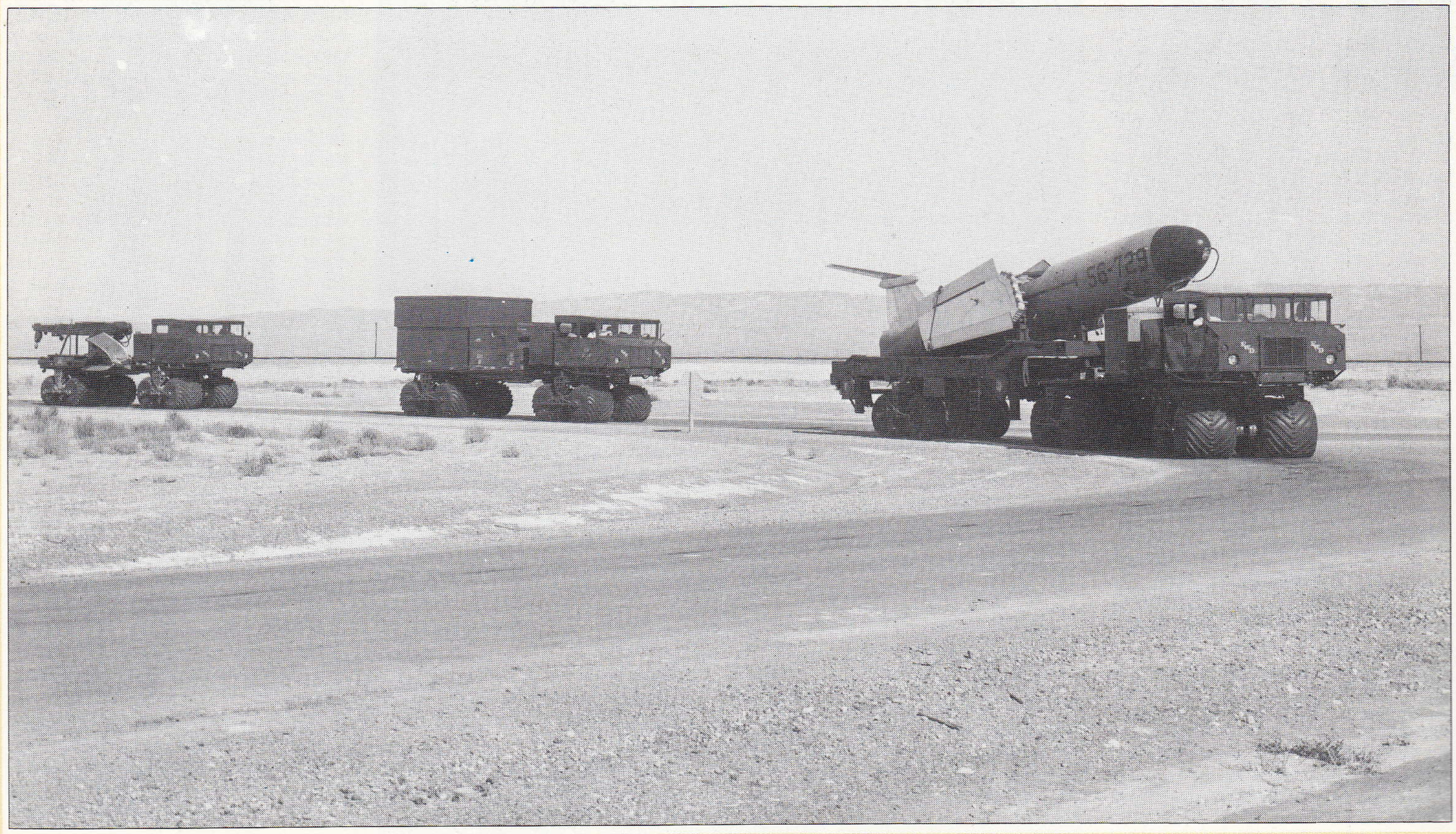
When the ICBM was a new creation it was often called 'the ultimate weapon'. There was no existing defence against it. Gradually, ways were found to filter out the real warheads from the penaids and then destroy the warheads at a safe altitude above their targets. Today many clever methods are known, but no actual ABM (anti-ballistic missile) defences exist except in the Soviet Union, where the ABM installations are the biggest weapon constructions of all time. There is little point in devising a way to protect one's self against attack if the knowledge is not to be used.

By comparison, the winged cruise missile appears easy to shoot down. The UK, starting from scratch in July 1944, shot down 4,261 of about 8,000 V-1 missiles which crossed the coast (of 9,251 fired). Modern defences could in theory destroy every cruise missile, despite the latter's ability to try to look invisible (by 'stealth' technology) and to take evasive action. The cruise missile certainly poses a threat, countering which probably costs an enemy more than the cost of the missiles. But for maximum deterrence there seems no alternative to the modern mobile (or submarine-fired) ballistic missile.



Above: In contrast to ICBMs, the first generation of cruise missiles did not require elaborate ground facilities before launching. This meant that intercontinental systems such as the Northrop SM-62 Snark could be mobile, reducing their vulnerability to attack.

Below: The Martin Mace, together with its launch facilities, could be moved around in small convoys in much the same way as the modern cruise missile. Once on site the missile would be assembled and launched from a portable ramp.



UK

English Electric Blue Water

Like almost all the dozens of British military aircraft and missiles of 1955-65, the excellent **English Electric Blue Water** tactical missile had the misfortune to be British. Because of the political environment this practically guaranteed that nothing would be done with it, even though it was technically far in advance of similar weapons in other countries. Its development was authorized in 1958, to meet a War Office requirement for what was called a 'corps-support weapon'. This was to replace the obsolete Corporal, and it was logical to give the job to English Electric Aviation at Stevenage, which had been foster-parent to Corporal in the British army. The specification was much more severe than that of the contemporary Sergeant, calling for numerical maximum/minimum ranges, immunity to countermeasures, harsh demands on air-portability, and very low bulk, system price and cost. The Blue Water missile was amazingly small for its task, and after trials with a special triple-launcher vehicle it was found possible to put the entire weapon system aboard a standard Bedford 3-ton truck, except for a small self-checking digital computer. The whole system could be slung under a Bristol Belvedere helicopter. When a target was identified the computer vehicle drove up on one side and fed in trajectory, motor cut-off time and warhead burst height, while a theodolite set up the inertial platform by looking through a hole at a mirror inside the missile. The whole procedure took about two minutes, after which the missile could be elevated to the correct angle and fired. Trials went outstandingly well, and this should obviously have become a standard NATO weapon, the Standing Group having announced a European need for just such a missile. In 1962 British political ineptitude resulted in the Blue Water being cancelled in favour of the Sergeant, which had greater circular error, was a far less convenient system weighing three times as much and possessing a reaction time nine times longer, at five times the cost.

Specification

Blue Water

Type: truck-mounted tactical precision missile

Propulsion: high-impulse dual-thrust solid-propellant motor

Performance: cut-off/burn-out velocity typically 2414 km/h (1,500 mph); maximum range 100 km (62 miles)

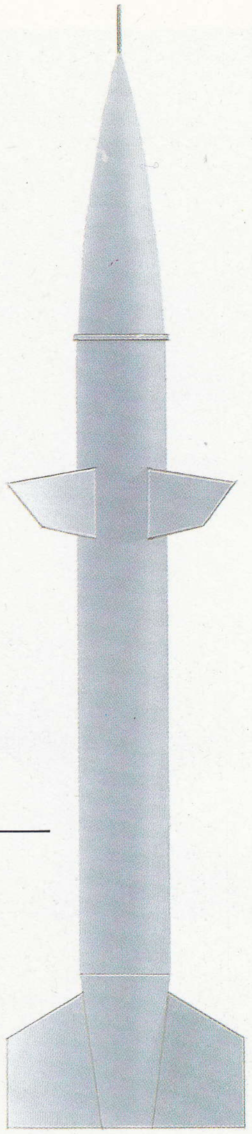
Weight: launch 1361 kg (3,000 lb)

Dimensions: length 7.62 m (25 ft 0 in); diameter 0.61 m (2 ft 0 in)

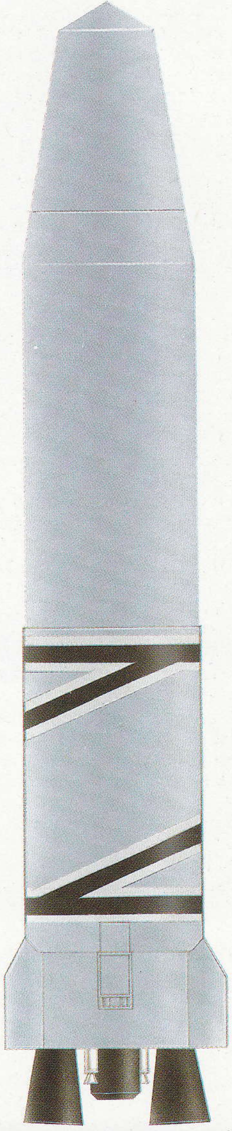
Warhead: three quick-change heads, normally travelling with 2-kiloton nuclear

Guidance: strapdown inertial

Control: four moving wings around mid-section



Left: One of the finest tactical missiles ever produced, Blue Water was extremely accurate, with advanced propulsion and guidance, and could be set up for launch in two minutes. It was cancelled in favour of the much less effective, much heavier and much slower-reacting Sergeant, which had the good fortune to be an American system.



Right: Blue Streak fell victim to the erratic defence policies of the early 1960s. Using Atlas technology, the missile had a range of 4627 km (2,875 miles). It survived military cancellation as a potential space launcher, but the programme was eventually terminated.

UK

de Havilland Blue Streak

Like almost all the UK's other combat aircraft and missiles, the **de Havilland Blue Streak**, a large and important weapon system, was cancelled after having been described as 'the ultimate defence system of this country'. The decision to deploy a British strategic thermonuclear missile was taken in January 1955. Orders for the system, which never had any popular name except its original codename, were placed with de Havilland Propellers as prime contractor, de Havilland Aircraft for the airframe, Rolls-Royce for propulsion and Sperry Gyroscope for the guidance. To save time and reduce risk the technology was copied from that of the Atlas, though in many respects even more primitive design solutions were adopted. Thus the stainless-steel 'balloon tank' airframe had blunt-cornered fairings over the two thrust chambers, and the latter had conical expansion nozzles instead of the more efficient hyperbolic-curve type as used on Rocketdyne production engines. System design and integration was centred at Hatfield, engine testing at an extensive establishment specially built at Spadeadam, Cumberland, and flight test at the Weapons Research Establishment, Woomera, Australia, where full-range flights were possible. The operator was to be RAF Bomber Command, whose Blue Streak squadrons were to store their missiles on rotating tables made by Morfax in deep hardened silos in the UK and on sovereign base areas elsewhere. Before launch the table was to be raised rapidly to the surface, with high-rate loading of the propellants and final transfer of target data to the guidance system and rotation to the launch azimuth. In 1956 it was said the Avro 730 supersonic bomber would replace the V-bombers; in 1957 the Avro 730 was cancelled, to be replaced 'by the forthcoming ballistic missile'; in early 1960 the Minister of Defence said 'Whatever happens, we shall keep Blue Streak'; in April 1960 the Blue Streak was cancelled, to be replaced by the US-designed Skybolt; and in December 1961 Skybolt was cancelled. The Blue Streak survived for a while as a civilian space launcher, setting a flawless flight record, only to be replaced by France's Ariane.

Specification

Blue Streak

Type: LRBM (long-range ballistic missile)

Propulsion: one Rolls-Royce RZ.12 package with two RZ.2 lox/kerosene engines each with sea-level rating of 62142 kg (137,000 lb), and two Armstrong Siddeley PR.23 vernier motors each rated at 227 kg (500 lb)

Performance: cut-off velocity Mach 15.5; maximum range 4627 km (2,875 miles)

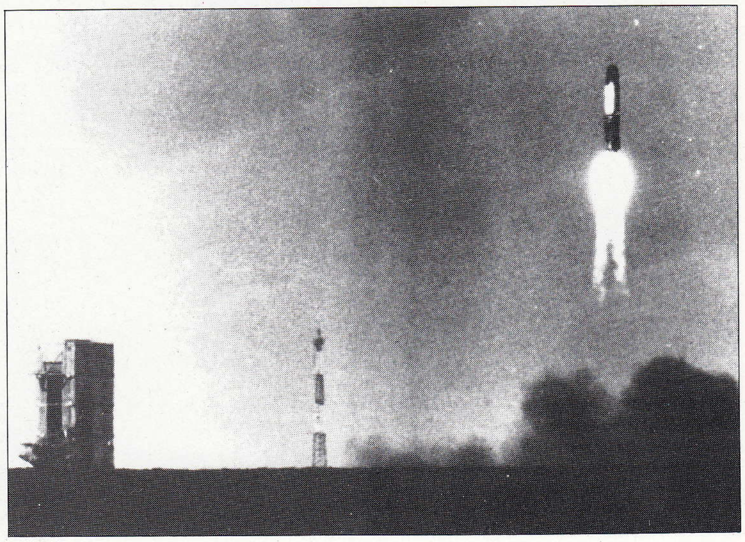
Weight: launch 90265 kg (199,000 lb)

Dimensions: (GE Mk 1 RV) length 18.75 m (61 ft 6.2 in); diameter 3.05 m (10 ft 0 in)

Warhead: thermonuclear, possibly 1.5-2 megatons

Guidance: inertial

Control: thrust vectoring of main-engine gimballed chambers and verniers, with vernier trimming of final velocity



Blue Streak, flight-tested in Australia, would have been a significant component of the United Kingdom's strategic deterrent, although any deployment sites would have been as vulnerable as the US Atlas system.

USSR

SS-3 'Shyster'

Said at the time to be designated **T-1**, this missile was revealed in the 1957 October Revolution parade through Red Square, Moscow. It was the first Soviet ballistic missile to be seen, and it was carried on a four-wheel trailer (very like the A4 *Meillerwagen*) towed by a 309.5-kW (415-hp) AT-T heavy artillery tractor which seated the launch crew of 16. Classed as an MRBM (medium-range ballistic missile), this weapon marked a major technical advance beyond the A4, though derived from the German missile. The engine was developed at the Leningrad-based GDL, and differed from the earlier RD-100 in having a solid catalyst to drive the gas generator and turbopump, and in being improved mechanically throughout. Propellants were liquid oxygen and a 93 per cent solution of ethyl alcohol, and the vehicle control was derived from the A4. The pointed nosecone, which did not separate, contained a nuclear, conventional or chemical warhead. Radio command guidance was based on use of several ground stations at surveyed sites, but it was claimed that missiles could be launched 20 minutes after arriving at the firing location. Test firings took place in 1949 and large numbers were deployed in 1955, receiving the US/NATO appellation **SS-3 'Shyster'**. A few of these missiles were reported to have been converted in about 1958 to lox/kerosene propulsion. The next generation was the longer **SS-4 'Sandal'**, the cause of the Cuban 'missile crisis' in 1962. This had the much more powerful GD-214 engine with four chambers burning RFNA (acid) and kerosene, rated at 73520-kg (162,084-lb) thrust at sea level and carrying a 1-megaton thermonuclear warhead.

Specification

SS-3

Type: mobile MRBM

Propulsion: one GDL RD-101 pump-fed rocket engine burning lox/alcohol and developing a sea-level thrust of 37730 kg (83,180 lb)

Performance: burn-out/cut-off speed about Mach 7; maximum range 1200 km (746 miles)

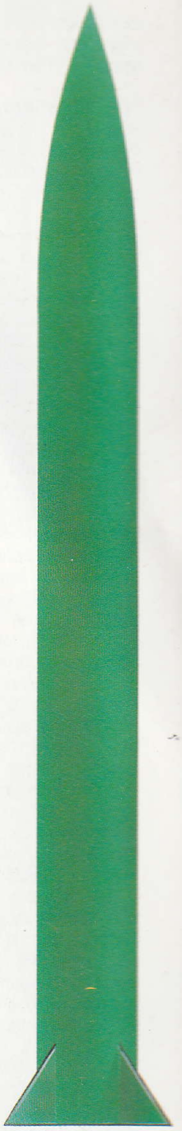
Weight: launch 26000 kg (57,320 lb)

Dimensions: length about 21.00 m (68 ft 10.8 in); diameter 1.70 m (5 ft 6.9 in)

Warhead: usually nuclear (yield not known, but later SS-4 was thermonuclear)

Guidance: originally radio command, later radio-inertial

Control: four jet deflector vanes and four aerodynamic control fins; vernier velocity trimming believed absent

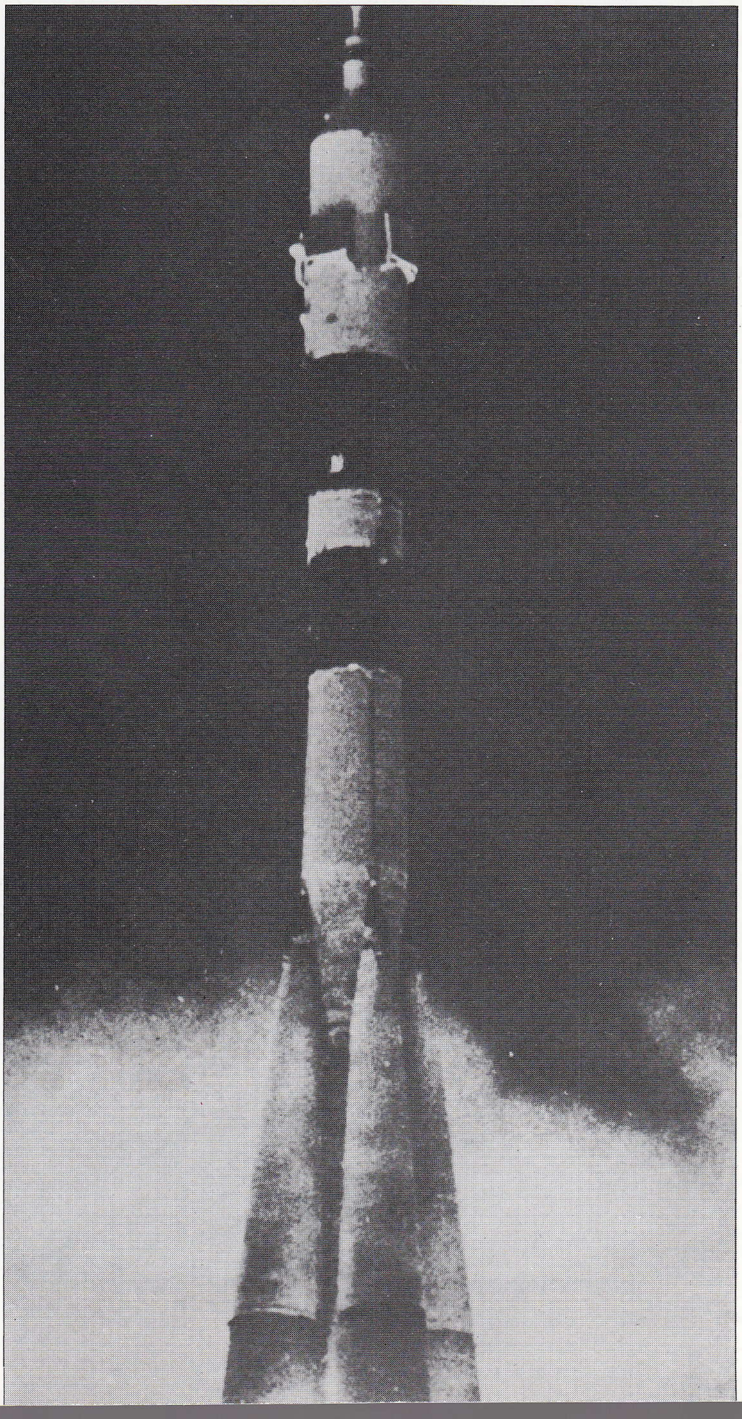


Derived from the German A4, the T-1 missile (known to NATO as the SS-3 'Shyster') was first fired in 1949 and was deployed in large numbers in the 1950s. It had a range of 1200 km (746 miles).

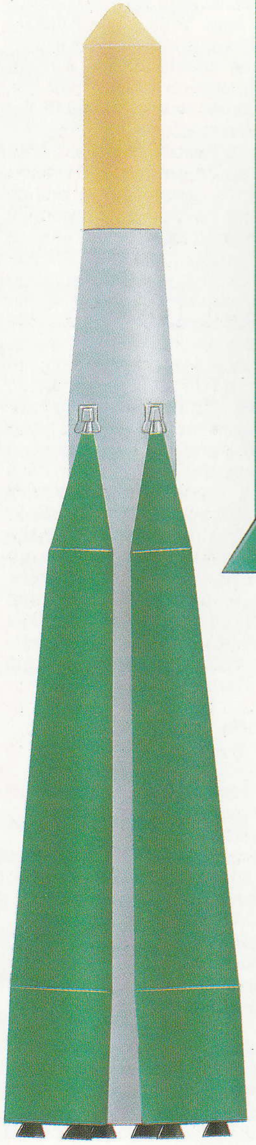
USSR

SS-6 'Sapwood'

This gigantic missile typified the basic Soviet approach to solving problems: the use of brute force. Though topped by the towering SS-18 now in use, the **SS-6** 'Sapwood' (the designation and name are Western inventions) is the heaviest weapon projectile of all time, with a lift-off weight greater than that of any known aircraft except the largest of the wide-body airlines. It was planned in 1953 to guarantee that a long-range 'carrier rocket' would be available to deliver Soviet thermonuclear warheads. Cost was completely discounted, and the immense size of the weapon naturally caused no public outcry (such as would happen in the West) because no announcement was made. The configuration remains unique. The vehicle at lift-off comprises (the present tense is used because the same vehicle is in current use as a space launcher) a central core with four tapered strap-on boosters, the latter also to some extent serving as fins. The core is powered by an RD-108 engine with four fixed thrust chambers and four small vernier engines, all fed by the same turbopump group. Each of the boost packages has four thrust chambers forming an RD-107 engine which also includes twin vernier motors gimballed through 45° each side of vertical. Thus at lift-off the whole gigantic vehicle has 32 rocket engines, all firing simultaneously! The first test firings cannot have been later than the start of 1956, and a full-range firing took place on 21 August 1957. Deployment must have posed immense problems. This giant vehicle became known after one had placed *Sputnik 1* in orbit on 4 October 1957, and it was then seen that it needed a vast launch complex which included a large-scale electric railway. Probably only a dozen or two of these missiles were actively deployed, though much greater numbers have been used in subsequent space launches. The SS-6 carried the heaviest warhead ever



The size and power of the R-7 missile made it an ideal launcher for the first space vehicles. Launching the first Sputniks and the first cosmonaut, the launcher versions of the R-7 were the power behind the early Soviet triumphs in the race for prestige in space.



Above: The heaviest weapon projectile of all time, the 300-ton R-7 (known as the SS-6 'Sapwood' to NATO) was the first genuine ICBM to enter service. Powered by no less than 32 rocket engines, the gigantic missile had the highest throw weight ever recorded.

SS-6 'Sapwood' (continued)

constructed for any missile, though its yield has been surpassed by that of single-RV SS-18 missiles.

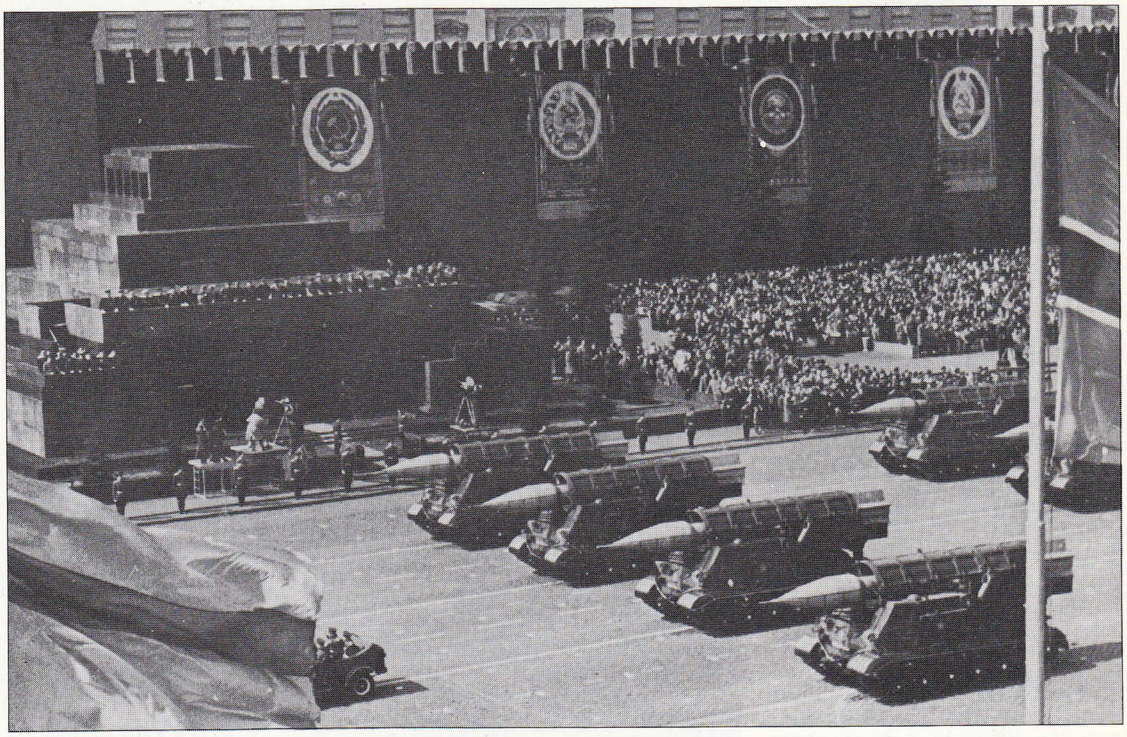
Specification

SS-6
Type: fixed-base ICBM
Propulsion: one RD-108 package with four thrust chambers (sea-level rating of 77500 kg/170,858 lb) and four verniers, plus four boost packages each with one RD-107 with four thrust chambers (vacuum rating of 104010 kg/229,303 lb) and twin verniers, all burning liquid oxygen and kerosene.
Performance: cut-off/burn-out velocity Mach 26; maximum range over 10000 km (6,214 miles)
Weights: basic structure 28000 kg (61,729 lb); lift-off total over 295000 kg (650,364 lb)
Dimensions: length 30.50 m (100 ft 0.8 in); diameter (each of the five components) 2.95 m (9 ft 8.1 in)
Warhead: 6800-kg (14,991-lb) thermonuclear, yield estimated at 5 megatons
Guidance: complex radio/command/inertial
Control: thrust vectoring of 12 vernier engines

USSR

FROG-1 and FROG-2

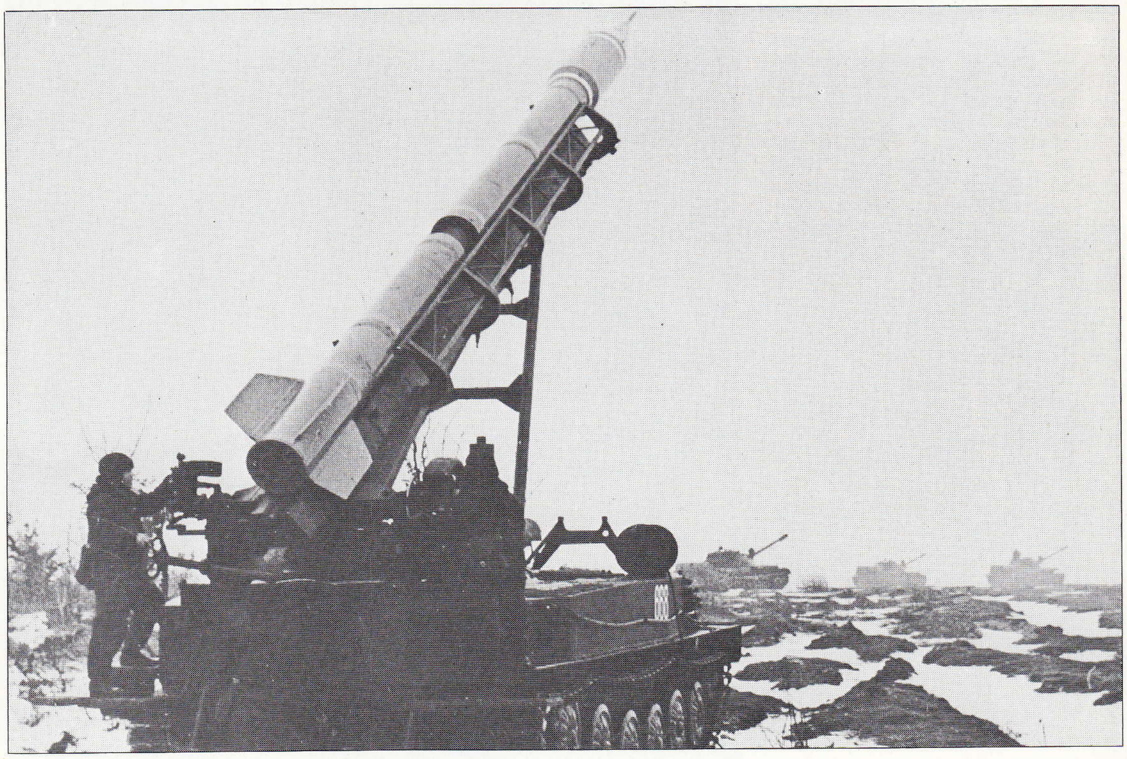
This odd name is a US acronym, from 'Free Rocket Over Ground'. It has been applied to a long and prolific series of Soviet artillery rockets whose first three members, when they were revealed in the October Revolution parade through Red Square in November 1957, were said to have had the designations **T-5A**, **T-5B** and **T-5C** (though there has never been any confirmation of this). All FROG missiles are simple ballistic rockets carried on tracked vehicles and used in connection with a land battle. The **FROG-1** was the only version carried (on surplus IS-3 tank chassis) inside a drum container. It was suggested that this massive cylinder was to maintain the solid-propellant rocket motor at above freezing temperature in winter. Like all subsequent versions, the FROG-1 was aimed by steering the launch vehicle, using its tracks, the azimuth (bearing) being capable in some installations of refinement over a small angle by rotation on a pivot. The range was then determined by selecting the correct launch elevation angle. The **FROG-2** was a smaller and lighter missile which could be carried on the amphibious PT-76 light tank, giving almost perfect cross-country capability. With many thousands of both types of launch vehicle available, production of these powerful rockets was on a scale which by Western standards seems astronomical. Many thousands were fired during exercises in the 1960-80 period. Only later versions are in service today, fired with two-stage propulsion from high-performance ZIL-135 wheeled cross-country vehicles, though some of the earlier versions are probably still to be found in smaller or Third-World countries.



Above: The simplest approach to ballistic missiles is typified by the Soviet FROG series. FROG-1, carried in cylinders aboard converted IS-3 tank chassis, was aimed by pointing at the target, and range was achieved by choosing the relevant launch angle. Naturally, such a system would be somewhat inaccurate, but it served in such large numbers that targets could be saturated with high explosive.

Specification

FROG-1
Type: unguided spin-stabilized artillery rocket
Propulsion: large solid-propellant motor with cast charge, and single expansion nozzle (later versions have multiple nozzles)
Performance: estimated burn-out speed Mach 2; estimated maximum range 32 km (20 miles)
Weight: launch 3000 kg (6,614 lb)
Dimensions: length about 10.00 m (32 ft 9.7 in); body diameter 0.85 m (2 ft 9.5 in)
Warhead: usually large conventional; all FROG versions also have the option of a chemical warfare head, and FROG-1 and certain other versions could also carry a tactical nuclear head
Guidance: none
Control: spin stabilization only



FROG-2 and FROG-3 were mounted on PT-76 amphibious tank chassis, and many thousands were fired on exercise in the 1960s and 1970s. They were used on Israeli targets by Syria in the Yom Kippur war of 1973.